Mellon Institute of Industrial Research and School of Specific Industries

Smoke Investigation

Bulletin No. 8

Some Engineering Phases of Pittsburgh's Smoke Problem

University of Pittsburgh
Pittsburgh, Pa.
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There is nothing impossible or wonderful about the smokeless combustion of even Pittsburgh coal, provided the proper methods are applied and the ordinary precautions taken.

Figure 1—Map of Pittsburgh and vicinity.

Contents.

Illustrations.

Note.

The work on this report was begun in March, 1912, under the direction of Mr. A. B. Bellows. The work was outlined by him and the field work carried on under his supervision until May, 1913, when he was compelled to resign because of illness. The work was then taken up by Mr. A. A. Straub, who had joined the Engineering Staff of the Investigation in December, 1912. The material was assembled and the report was written, for the most part, by him. Mr. Straub remained with the Investigation until June, 1913. All of the field work in connection with the report was done by Mr. O. R. McBride.

The outline for the survey of plants in this report is similar to that developed in Bulletin 40 of the United States Bureau of Mines, "The Smokeless Combustion of Coal in Boiler Furnaces," by D. T. Randall and H. W. Weeks. The authors of this report are indebted to these men. Acknowledgment is made to Mr. A. F. Nesbit for revising and reviewing the report. The drawings for the line cuts were kindly furnished by the various boiler, furnace and stoker companies. The photographs of the city and of the maps were taken by Mr. Harry C. Anderson.

No bibliography is appended to this report because it is expected that those who receive it either have copies of, or at least, have access to copies of Smoke Investigation, Bulletin No. 2, Bibliography of Smoke and Smoke Prevention.

JOHN O'CONNOR, JR.

February 23, 1914.

Introduction.

This report was made with the view, first, to determine the conditions which, existing in the Pittsburgh District, account for so much smoke in the District and, second, to describe the methods of furnace construction and the existing mechanical or other devices, the employment of many of which aids materially in securing more perfect combustion of fuel and lessens the amount of smoke produced.

The smoke nuisance is no new problem in Pittsburgh. It has been a sore spot since the very beginning of the city. The city, in the minds of some, seemed to have thrived on smoke and it came, in time, to be a symbol of prosperity. It is only at this late day, in the light of an ever growing civic consciousness, that the city is coming to realize that the smoke nuisance is the greatest handicap with which it has to contend.

Pittsburgh's smoke problem is unique in many ways and there are extenuating circumstances connected with it. It is well known that the District is located in the heart of the bituminous coal fields, the coal from which, being very rich in volatile matter, is difficult to burn without smoke. The industries of the District use more bituminous coal than any other district of like size in the world. Pittsburgh's topography, which bears the brunt of so many of Pittsburgh's evils, while no cause of the smoke nuisance, intensifies and prolongs it. Pittsburgh's irregular topography confines the smoke in "pockets" so that it cannot be readily carried away by the winds. A study of the topography will reveal the fact that the non-production of smoke is the only solution of Pittsburgh's smoke problem.

Arguments which are advanced in other cities against the smoke nuisance have not the same value when they are advanced in Pittsburgh. It is so with the argument that

smokeless combustion is economical. Efficiency tests of plants and mills may not reveal a very large monetary saving, under the most favorable conditions of operating, when fuel is $1.25 or less per ton. The mechanical engineer has no light task before him, in his attempt to demonstrate conclusively that a redesigning of combustion chambers, the proper mixture of air and volatile gases, and the employment of automatic devices for feeding the fuel, will result in the greatest economy and at the same time minimize the production of smoke. More than that, it is sad to relate, that the mechanical engineer is seldom called in by the owner of a Pittsburgh plant. The plant owner, as a rule, seeks advice from someone who has this or that apparatus to sell him. The Pittsburgh District should be the greatest center in the world for combustion engineers. There is a need, but no great demand for them.

However, the outlook for smoke abatement in the Pittsburgh District is most hopeful. With the introduction of modern ideas of efficiency, the plant owner will be forced to look, where so few have as yet looked, into the boiler room to see what savings can be affected there. In doing this he will, moreover, be prompted and urged by a sense of duty and responsibility to the community, which is more and more coming to demand that the smoke nuisance be abated as a menace to health, property and the things which make for civic betterment.

Summary of Conclusions.

That there is a reason for such a report as the present one is evidenced by the fact that when smoke observations were made on the stacks of the one hundred and fifty-two stationary plants, described in this report, about forty per cent. of them were violating one of the most lenient smoke ordinances of any large city of the United States. Fifty per cent. of the stacks of the hand-fired plants and sixty per cent. of the stacks of the front-feed stoker plants were violating the ordinance. The percentages of violations from the other types of stationary plants were small.

The two main sources of smoke in the city and district are the manufacturing plants, which include special furnaces, and the railroads. The amount of smoke made in the business and in the residence sections is relatively small.

In the manufacturing plants, on account of the cheapness of fuel, slight attention is paid to the efficiency of the boiler plant and little effort is made to prevent smoke in heating or metallurgical furnaces. Because of the conditions which prevail in the majority of plants the average boiler efficiency is from fifteen to twenty-five per cent. lower than what it should be. If the necessary changes were made in these plants and the proper care taken, it would not be unreasonable to expect a thirty per cent. decrease in fuel consumption.

The next worst offenders to the manufacturing plants, in the emission of smoke, are the railroads. Inasmuch as all outbound locomotives have to ascend heavy grades they make much smoke. However, most of the smoke is made in the yards by shifting engines. There seems to be only one sure cure for this, and that is that they use some fuel which does not produce objectionable smoke as, for example, coke. Probably, the ultimate solution of the railroad smoke problem is electrification. A strenuous demand for smoke abatement will hasten its coming.

A small group of men control the plants which produce at least eighty per cent. of the smoke of the district. The solution of Pittsburgh's smoke problem lies in inducing these men to apply the best of modern engineering practice to the combustion of fuel in their plants. *There is nothing impossible or wonderful about the smokeless combustion of even Pittsburgh coal, provided the proper methods are applied and the ordinary precautions taken.*

Part I.

The History of the Smoke Nuisance and of Smoke Abatement in Pittsburgh.

The history of the Smoke Nuisance in Pittsburgh dates from the very beginning of the city. Tradition has it that coal was burned in Fort Duquesne by the French. As this coal was from the Pittsburgh vein, which is so rich in volatile matter, and as it was burned, no doubt, as a great part of it is burned to-day, it is safe to assume that there was black smoke about the Fort even in its earliest days. The Rev. Charles Beatty, who was chaplain of the English forces which occupied the Fort in 1758, noted that coal was used in the garrison in 1766. In that year, what was known as "Coal Hill," now Mount Washington, took fire and is said to have burned steadily for sixteen years.

A Town Problem 110 Years Ago.

That official cognizance was early taken of the Smoke Nuisance is indicated in the following communication of General Presley Neville, the Burgess of Pittsburgh, to George Stevenson, the President of Council. The letter is dated June 10, 1804. It reads in part:

"The general dissatisfaction which prevails and the frequent complaints which are exhibited, in consequence of the Coal Smoke from many buildings in the Borough, particularly from Smithies and Blacksmith Shops, compels me to address you on this occasion. I would be extremely sorry to be in any way the means of subjecting any of our fellow citizens to unnecessary or useless expense, but in this instance not only the comfort, health and in some measure the consequence of the place, but the peace and harmony of the inhabitants, depend upon

the speedy measures being adopted to remedy the nuisance."

The burgess went on to suggest higher chimneys by which "the smoke could be voided into free air and carried beyond the limits of the Borough."

First City Legislation.

Although the attention of Pittsburghers was constantly called by officials and more especially by visitors, to the evils of the smoke nuisance, no legal regulation was attempted until shortly before 1869.

In the digest of the ordinances of Pittsburgh, 1804-1869, there is recorded the following ordinance:

"Section 2344. No bituminous coal or wood shall be used in the engine or any locomotive employed in conducting trains upon any railroad."

The code in which this ordinance appears was formulated in 1869 so this ordinance was passed, no doubt, shortly before that date. It is said that it has never been expressly repealed or amended.

The Coming of Gas.

There is no reason for believing that this ordinance was very seriously enforced. There are, however, good reasons for believing that Pittsburgh would never have had any smoke abatement agitation, as early as it did, if it had not come to pass that the city was practically freed from smoke by the discovery of natural gas and its utilization as a fuel. In a report made to the Engineers' Society of Western Pennsylvania in May, 1884, there was this statement: "Smoke and smoked ceilings of Pittsburgh may become things of the past, yet if sold at the price now charged, *i. e.*, 50c per thousand feet, it (natural gas) is much more costly than coal." At the time of the report, natural gas was being used as a fuel in the Union Iron Mills and the Black Diamond Steel Works. It was only a short time until natural gas became cheaper than coal and for the time being supplanted the latter as a fuel.

Engineers' Society.

However, before 1885 Pittsburgh became alive at least to the question of coal economy. In 1881, William Metcalf, an eminent engineer and mill owner, read a paper before the Engineers' Society of Western Pennsylvania on "Some Waste of Heat." In the introduction to his paper he declared that he "proposed to show by figures obtained from actual working data, how much money is annually thrown away in Allegheny County by throwing coal into our furnaces in the shape of coal, to be sent, wasted, out at the tops of the stacks in the shape of dirty, useless smoke, and red and far more expensive flames." He estimated the cost to be $1,063,000.

In 1884 it is estimated that Pittsburgh was using annually 3,000,000 tons of bituminous coal. With the introduction of natural gas this fell off to less than 1,000,000 tons. The regime of natural gas was brief. About 1890 the coal consumption again began to move upward and by 1895 King Coal had resumed his throne.

Lesson of a Clean City.

But Pittsburgh knew what a clean city was like. It had actually been experienced. It was only natural then that the people protested when the smoke began to increase. The question was taken up by the Ladies' Health Association of Allegheny County. The prime mover in this organization was the late Miss Kate C. McKnight, who was very active in civic work. This association merged with the Civic Club of Allegheny County when it was organized in 1895. A committee from the Health Association was present at the meeting of the Engineers' Society in February of 1892 when William Metcalf, referred to above, read a paper which was a partial defense of smoke. In the discussion that followed this paper one of the speakers said:

"We are going back to smoke. We had four or five years of wonderful cleanliness in Pittsburgh, and we have all had a taste of knowing what it is to be clean."

At the March meeting of the Engineers' Society, the Ladies' Health Association presented its side of the story. The result was that the engineers appointed a Committee on Smoke Prevention, which reported in the latter part of the same year.

Action by the Engineers' Society.

In this report the committee recommended: (1) That the Women's Health Protective Association or some similar organization, continue its efforts toward smoke prevention by educating the community in its principles and advocating the use of smokeless fuel in dwellings and the best stokers or other devices in manufactories and steam plants. (2) That the City Council should pass an ordinance for the abatement of the Smoke Nuisance, insisting on the absence of dense smoke from stationary, steamboat and locomotive boilers except when fires are started, but recognizing the necessity of puddling and other furnaces which require a small excess of carbon for proper working. (3) That one of the duties of the Building Inspector or of persons appointed for the purpose, should be to see that the newly erected buildings have properly designed flues and ample room for furnaces with particular reference to economical combustion and the non-emission of smoke.

It is interesting to note that in this first report on the smoke nuisance, the importance of having all plans and specifications for the installation of boilers and furnaces come under the supervision of a properly qualified inspector, was recognized and emphasized. It is also interesting to note that scarcely a year has passed since the founding of the Engineers' Society, a committee from which formulated the above mentioned report, but that a paper dealing with some phase of the smoke problem has been read before it. Practically every phase of the problem as it affects both the producer of smoke and the business and general public who suffer from its effect, has been presented before the Engineers' Society.

First General Ordinance.

There is little doubt that as a reult of the agitation on the part of the Ladies' Health Association, and because the city was forced to give up the use of gas in the pumping station, in 1891, on account of the increased price, the City Councils passed the first general ordinance.

This ordinance of March, 1892, provided that after September 1, 1892, it should be unlawful for any chimney or smoke stack used in connection with a stationary boiler to allow, suffer or permit smoke from bituminous coal to be emitted or escape therefrom, within a certain district. This district was bounded by Miltenberger, Dinwiddie, Devilliers and Thirty-third streets on the west and the city line on the east. Its northern and southern boundaries were irregular, being arranged according to a newspaper, "so as not to affect a number of iron works, steel works, oil refineries and other industries for which successful smoke consuming devices have not yet been provided." It will be observed that this ordinance excepted the business section of the city, bounded by Grant street, the Tenth street bridge and the two rivers. The ordinance was chiefly notable for its exceptions. The power of enforcing this ordinance was placed in the hands of the Department of Public Works.

Efforts at the Pumping Station.

Edward M. Bigelow, who was then Director of the Department of Public Works, assigned the duty of enforcing the ordinance to the Superintendent of the Bureau of Water Supply. The city decided very properly to clean up its own stacks, which were sending forth black smoke, and at the same time to give a demonstration of what might be done in the way of burning bituminous coal for steam making purposes without emitting black smoke.

The story of the attempt to make the Brilliant Pumping Station smokeless is a most instructive one. No doubt it explains why plants other than municipal ones are still making black smoke. At first the work at the pumping

station was pushed with vigor. The work of installing stokers was started in 1893. In 1894 the Superintendent said in his report: "None of the smokeless devices are smokeless except under favorable conditions." Mr. Bigelow, the Director of the Department of Public Works, was more optimistic, for in his report for that year he said: "I may say that we have solved the problem of smoke prevention at the pumping stations." In 1908, the Superintendent reported: "We have continued our efforts to prevent an unnecessary amount of smoke at this station."

It is interesting to note in connection with the review of the efforts put forth by the city at the Brilliant Pumping Station that in his 1913 message to Council, Mayor Magee said, "Your attention is called again to the fact that one of the worst offenders against the smoke ordinance is the City of Pittsburgh at the Northside light plant and the Brilliant Pumping Station."

In May of 1895 a second smoke ordinance was passed. This ordinance provided in Section 1, that the emission of more than 20 per cent. black or dark gray smoke from any stack should be considered a public nuisance. Section III provided a fine for the emission of smoke for over three minutes. The decision of the Superior Court in the case of Pittsburgh vs. W. H. Keech Company virtually made this ordinance inoperative.

The Work of the Chamber of Commerce.

In January, 1899, the President of the Chamber of Commerce, appointed a Committee on Smoke Abatement. This appointment was, no doubt, brought about in a measure by the speech of Andrew Carnegie at the annual banquet of the Chamber in November of 1898. In speaking of the Smoke Nuisance he said: "We all know that many of our citizens are tempted just at that period of their lives when they would be of most use to our city, in furthering the things of a higher order, to leave Pittsburgh to reside under skies less clouded than ours. The man who abolishes the Smoke Nuisance in Pittsburgh is

foremost of us all; to him be assigned first place, and to him let our deepest gratitude go forth."

After the appointment of its committee the Chamber of Commerce requested that a committee be appointed from the Civic Club of Allegheny County and from the Engineers' Society to co-operate with it. While the Civic Club promptly accepted the invitation, the Engineers' Society, for reasons of its own, withheld its co-operation. This combined committee reported in December of 1899. Among other things in this report, it said:

"If your committee believed that it was not practicable to, at least, greatly diminish the smoke nuisance throughout the commercial and residence districts of the city, it would frankly say so and ask for summary dismissal. * * * The efforts of our city government toward the abatement of the Smoke Nuisance have so far not met with notable success; a fact chiefly due to the absence of laws for the enforcement of the city ordinance for this purpose."[1]

The committee suggested asking the Legislature for power to compel offenders to comply with the ordinance.

Creating a Smoke Inspector.

As a result of the work of this committee an ordinance was passed in December, 1906. This ordinance held the emission of dense black or dense gray smoke for more than eight minutes in any one hour to be a nuisance and prescribed the penalties for the violation thereof. However, it made no provision for the enforcement of this ordinance by any particular bureau. In January of 1907, Council passed an ordinance introduced by this committee creating the office of Smoke Inspector.

At the request of Mayor Guthrie and in recognition of the efforts of this committee—this being prior to the enactment by the Legislature of the Civil Service Law—a civil service examination was held under the supervision of the committee to secure a man fitted to take the posi-

[1] Year Book and Directory, Chamber of Commerce, 1900.

tion of Smoke Inspector. William H. Rea was selected and active work was begun under the new ordinance in June, 1907. The administration of Mr. Rea was a very efficient one, resulting in a material reduction of the smoke nuisance in the city.

THROWN OUT OF COURT.

In 1909 Mr. Rea resigned and Mr. J. M. Searle was appointed by Mayor Magee to succeed him. On March 3, 1911, the ordinance was declared void in the case of the Commonwealth of Pennsylvania vs. Standard Ice Company. The grounds of this decision were, first, that the Legislature of Pennsylvania had likely not given the city any sufficient authority to pass ordinances upon the subject of the emission of smoke and without such authority the city could not act—this, however, was not definitely ruled—and, second, that the ordinances were unreasonable. On June 6, 1911, the Legislature passed an act authorizing cities of the second class to regulate the emission of smoke, and in September, 1911, a new ordinance—the present one with one modification, that of the exception of mill heating furnaces and puddling furnaces, was passed. On September 22, 1911, Mr. Searle resumed his work as Chief Smoke Inspector.

SMOKE INVESTIGATION OF MELLON INSTITUTE.

About the same time that Mr. Searle again took up his work as chief smoke inspector in 1911, a Pittsburgh business man provided Robert Kennedy Duncan, the Director of the Mellon Institute, with a fund for an investigation of the Smoke Problem. The present report is one of the publications issued by that Investigation.

Part II.

Evidences of the Smoke Nuisance.

Neither to those who live in, nor to those who even visit Pittsburgh or any other industrial center, which burns a large quantity of bituminous coal, is it necessary to present evidences of the smoke nuisance. The "smoke readings" given under the Survey of Plants gives some idea of general conditions. One need not be a smoke inspector to know that Pittsburgh has a smoke nuisance.

The interesting question is as to the extent of the smoke nuisance. The two sets of pictures given in this report will give an idea of what the actual conditions are and what they could be. The Smoke Investigation also made a study to determine the amount of solid matter in the atmosphere. This study gives a clue to the nature and extent of the nuisance in Pittsburgh.

Everyone is more or less familiar with the popular way in which explanation is given to account for the carrying of clouds of dust, ashes and smoke by the action of winds. During the existence of a calm or a very light breeze the dust, soot and other particles that issue from the chimneys or stacks rise to elevations which depend upon the draft artificially or otherwise produced. Many of these particles are, as a rule, quite light and because of this fact they settle very slowly to the ground or to their final resting places. While these particles are in the air they may float away to considerable distances, depending upon the circulation currents established in the atmosphere by their own upward motion, combined with the movement of large masses of the air due to meteorological changes.

The heavier particles in these clouds necessarily fall to the ground much sooner than the lighter ones. All along the pathway of such a floating cloud, dust or other

particles may be detected in greater or less abundance. There is reason to believe that the finer and lighter particles travel for many miles, especially when wind conditions are favorable. Similar phenomena are observable on an immense scale in the case of volcanic dust.

The atmospheric pollution may be due to the simultaneous existence of gases and fumes with the solid particles. The former are more or less invisible and are like the latter thinned out as they travel far away from their origin, until they finally disappear from view.

Study of Pittsburgh's Soot-Fall.

To determine the amount of solid matter in the atmosphere of Pittsburgh, its distribution and composition, twelve stations were selected in various parts of the city. The stations at which measurements were made, and their location, which may also be found by reference to the soot-fall map, Figure 2, are as follows:

Soot Collecting Stations.

	STATION.	LOCATION.	DISTRICT.
1.	Cargo School,	Boggs Avenue,	Mt. Washington.
2.	Ohio Valley Bank,	Preble Street.	Woods Run.
3.	Allegheny High School,	Sherman Avenue,	North Side.
4.	Oliver Building,	Smithfield & Sixth Ave..	Downtown Dist.
5.	Irene Kaufmann Settlement,	1835 Center Avenue,	Hill District.
6.	State Hall— University of Pgh.,	O'Hara Street,	Oakland.
7.	Peebles School,	Tecumseh Street,	Hazelwood.
8.	Ormsby Park,	S. 22nd Street.	South Side.
9.	Colfax School,	Phillips Ave. & Beechwood Blvd..	Squirrel Hill.
10.	Brushton School,	Brushton Avenue,	Brushton, Pa.
11.	Arsenal Park,	Butler Street,	Lawrenceville.
12.	Margaretta School,	Margaretta Street,	East Liberty.

Table I gives the weight of the soot-fall in grams at each station for each month. Below the table is given the calculated weight of the soot-fall at each station in tons per square mile for the entire year.

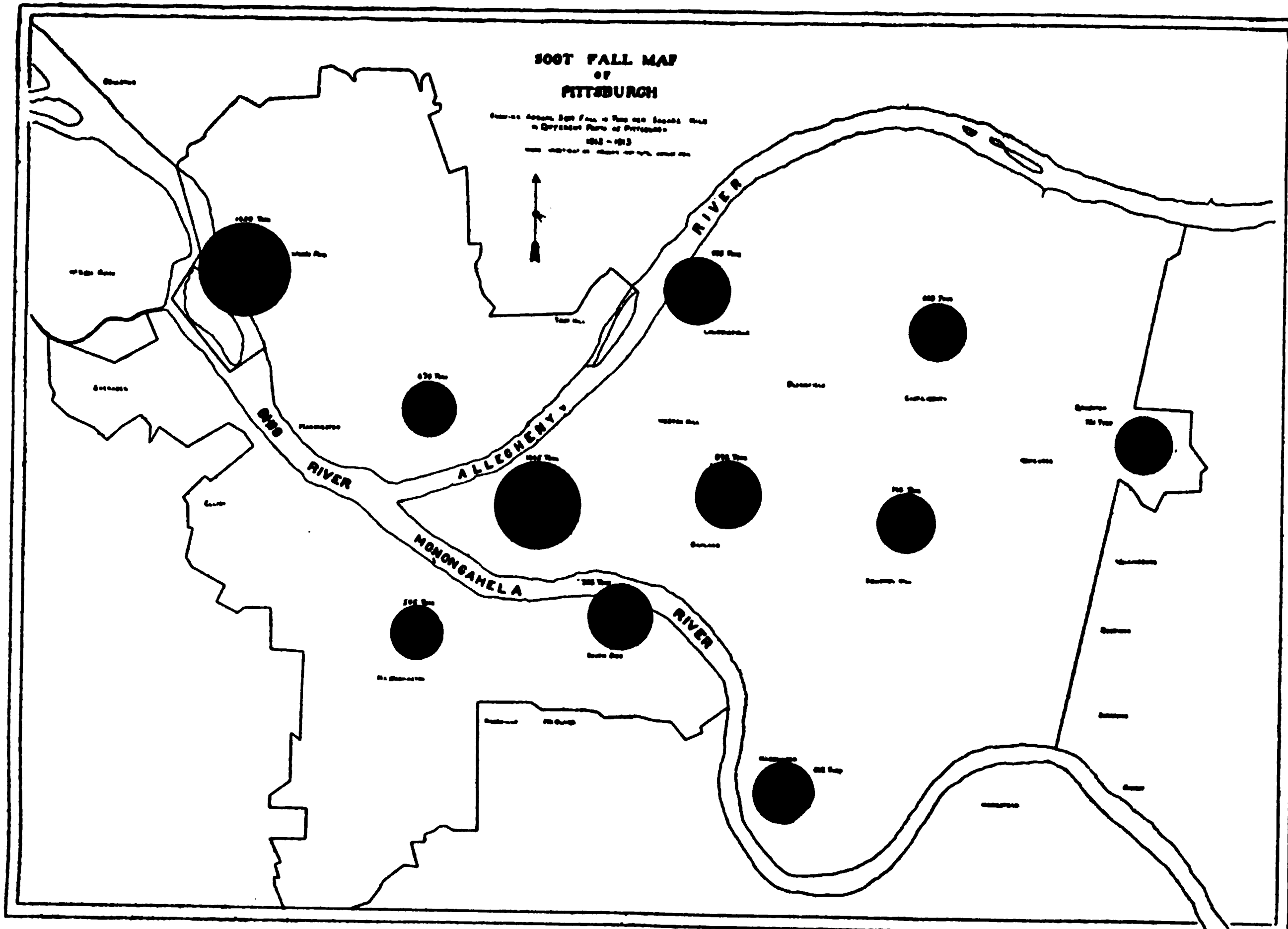

Figure 2—Soot-fall map of Pittsburgh.

TABLE I—PITTSBURGH'S SOOT-FALL SAMPLES IN GRAMS PER MONTH, APRIL 1912 TO APRIL 1913.

STATION NUMBERS.

Month.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
April, '12	.3806	.5106	.2722	.5308	.5501	.4186	.1184	.2596	.1821	.1341	.2599	.1603
May	.1081	.4146	.1142	.5198	.5882	.0873	.1384	.1915	.1332	.1192	.1676	.2778
June	.2552	.5714	.2752	.4872	.4000	.3604	.2142	.3306	.1863	.1374	.2026	.1315
July	.1450	.6924	.2570	.3900	.5520	.2282	.2030	.3364	.1732	.1564	.2678	.1938
August	.1104	.5154	.1460	.2608	.3570	.1828	.2022	.2266	.1732	.1142	.2024	.1210
September	.1114	.5038	.1910	.2022	.3278	.1830	.1832	.2040	.1826	.1282	.2136	.1426
October	.1380	.5610	.2182	.3124	.4622	.2488*	.2072	.3254	.1664	.1636	.2942	.1554
November	.0526	.7700	.1290	.2188	.3860	.2166	.2076	.1734	.1586	.1836	.2088	.1742
December	.1380	.7522	.3428	.4896	.3788	.3988	.2860	.1484	.4282	.3702	.4276	.2518
January, '13	.1278	.5232	.2660	.6398	.2828	.2742	.3092	.2456	.2094*	.3154	.3206	.1948
February	.1034	.6200	.2642	.4574	.3746	.2042	.0914	.1462	.1278	.1420	.2894	.1242
March	.1550	.5438	.1956	.5876	.3342	.1972	.3236	.3346	.1750	.2462	.1924	.1946
Total	1.8255	6.9784	2.6814	5.0964	4.9937	3.0001	2.4846	2.9223	2.2960	2.2075	3.0469	2.1220
Tons per sq. mi.	595	1,950	670	1,660	1,630	978	812	922	748	721	995	693

*The October jar from Station No. 6 was broken and the January sample from Station No. 9 froze and the jar was broken. The weights of the soot-fall were calculated by taking, in the case of the October sample of No. 6, the average per cent. of the October precipitate of the total of 12 months for the 10 full year samples. From this and the weight of No. 6 for 11 months the October precipitate was calculated. No. 9 for January was calculated in the same way. This gives a better weight than a simple average would.

TABLE II—PER CENT. ANALYSIS OF YEAR'S SAMPLE OF EACH STATION.

	STATION NUMBERS.											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Tar	2.19	0.82	1.56	1.12	1.26	0.36	1.00	0.74	0.62	0.42	0.76	1.04
Ash	75.84	62.6	68.30	73.77	76.82	66.68	61.94	68.20	71.16	61.42	59.96	70.14
Fixed carbon	21.97	36.58	30.14	25.11	21.92	32.96	37.06	31.06	28.22	38.16	39.28	28.82
Fe_2O_3 in ash	24.3	21.1	40.1	22.9	33.6	31.6	23.8	33.38	35.42	24.05	36.52	31.47
Fe_2O_3 in deposit	32.08	33.73	58.78	30.98	43.66	47.44	38.44	22.8	25.2	14.8	21.9	22.1

The soot collected at the different stations was analyzed according to standard methods. Table II shows the percentage of tar, ash, fixed carbon, iron oxide in ash and iron oxide in the entire deposit, of sample of soot-fall at each station.

The table given below shows the calculated amount in tons per square mile of tar, fixed carbon, ash and iron oxide that fell at the different stations during the stated year.

TABLE III—CALCULATED WEIGHT OF CHEMICAL COMPOSITION IN TONS PER SQUARE MILE PER YEAR.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Tar	13	16	10	19	21	4	8	7	5	3	8	7
Fixed carbon	131	713	202	417	357	322	300	286	211	274	391	200
Ash	306	809	189	844	704	343	309	419	344	336	378	333
Fe_2O_3	145	412	269	380	548	309	195	210	188	108	218	153

It is a matter of regret that similar soot-fall studies have not been made for other cities of the United States so that a comparison could be made of the amount of smoke in them. A number of studies have been made in cities of Great Britain. It was found, for instance, that in the city of Leeds the annual soot-fall varied from 26 tons to 539 tons per square mile. In 1910 observations were carried on in London and it was ascertained that the annual soot-fall in the center of London was 426 tons, while the average for the whole city was 248 tons per square mile. Observations made in Glasgow during the winter of 1910-1911 showed an annual soot-fall of 820 tons per square mile in the center of the city. When these figures are compared with Pittsburgh's average annual soot-fall of 1,031 tons per square mile, it would appear that either the methods of making calculations differ widely, or what appears to be the more plausible explanation—that Pittsburgh is a very smoky city.

Part III.

The Contributing Causes of the Smoke Nuisance.

While the underlying cause of the smoke nuisance is the incomplete combustion of bituminous coal, there are, as was stated in the introduction, what may be termed contributing causes of the smoke nuisance. In the first place, the coal which is found in the District is very plentiful, cheap and rich in volatile matter; secondly, the industries of the District are those which consume large quantities of coal. The District uses more bituminous coal than any other district of like size in the world. In the third place, the many hills and valleys, and the frequent fogs hold the smoke that is made long after it would have been carried away in another locality having a more regular topography.

THE COAL FIELD.

Pittsburgh, as is well known, is the center of the bituminous coal field of Pennsylvania. This coal field comprises an area of about 14,200 square miles; and it contributes 95 per cent. of the total bituminous output of the State, and one-third of the total bituminous output of the United States. The amount of coal originally in the bituminous field of Pennsylvania is placed at 112,574,000,000 short tons [1]. The total production to the close of 1911 amounted to 2,396,491,260 short tons. It is said that even at the present rate of exhaustion, the coal supply will still last about 475 years. It may be seen at once that Pittsburgh will be forced to battle with the smoke nuisance for years to come.

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1 United States Geological Survey—"The Production of Coal in 1912," by Edward W. Parker.

In 1912, 161,865,488 short tons of coal were mined in the District. The value of this coal was $1.05 a ton at the mine. The Pittsburgh coal, which is found in this field, is the most famous coal bed in America. The bed gives 9 feet of available coal over large areas, and seldom runs under 4 feet.

The Composition of Pittsburgh Coal.

Coal consists of moisture, ash, fixed carbon and volatile matter, the relative amounts of each varying considerably according to the locality or bed from which the coal is mined.

The moisture in coal is obtained by heating a finely powdered sample in a crucible for one hour at 104° to 107° C. The loss in weight represents the moisture. The amount of moisture varies from as low as 0.76 per cent. in the best grade of semi-bituminous coal to as high as 40 per cent. in the case of lignites. For coal from the Pittsburgh bed, the moisture contents in mine samples varies from below 1 per cent. to over 4 per cent.

Ash, which is ordinarily the mineral residue after the coal is burned, varies from as low as 2 per cent. in some West Virginia coals, to as high as 25 per cent. in dirty slack. Mine samples of Pittsburgh coal shows that the ash in it varies from 4.5 per cent. to 12.9 per cent.

Fixed carbon, which represents the difference obtained by subtracting the percentage of moisture, volatile matter and ash from 100 per cent., varies from as high as 80.6 per cent. in the better grades of semi-bituminous coal to as low as 33 per cent. in the poorer grades of bituminous coal. For Pittsburgh coal, fixed carbon varies from as low as 44 per cent. to as high as 59 per cent.

To obtain the amount of volatile matter in coal, one gram of a finely ground sample, placed in a covered platinum crucible is held over the full Bunsen burner for 7 minutes. The loss in weight represents moisture plus volatile matter. When the value of the moisture is subtracted from this result the remainder represents the

amount of volatile matter. In the best grades of semi-bituminous coal it will go as low as 12.3 per cent., while in some good grades it will run as high as 41.4 per cent.; and in the poorer grades, from 31.2 per cent. to 37.4 per cent. The volatile matter in Pittsburgh coal varies from 30.9 per cent. to 41.4 per cent. of the fuel [1]. As a rule, the amount of volatile matter may be considered a good indication of the smoke producing nature of the coal. However, volatile matter itself, varies in composition from that containing gases and compounds, which are not difficult of consumption in an ordinary furnace without the production of smoke, to that containing gases high in hydro-carbons in tar, which can only be burned without the production of smoke, in carefully constructed and operated furnaces. Pittsburgh coal, because of its volatile composition, is more smoky than other coals which have the same volatile content.

In order to understand why it is so difficult to burn the Pittsburgh coal without smoke it may not be out of place to discuss at this point the general process of combustion.

The process of combustion is a simple one, being a chemical union of the combustible material of a fuel with the oxygen of the air resulting in the development of heat. In practice, however, many difficulties are encountered which tend to complicate the process, and it is in overcoming these that care is required in the operation and construction of furnaces. The number and nature of the difficulties vary considerably with the fineness of the fuels, the type of furnaces used, the amount and composition of the impurities in the fuel, and the variable demands for power.

There are three separate and distinct stages involved in the combustion of coal. First, there is absorption of heat. When fresh fuel is fed to the furnace, its temperature must be raised to the kindling point in order that chemical combustion may begin. Second, in order, is the

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1 United States Geological Survey Professional Paper No. 48 and United States Geological Survey Bulletin No. 290.

distillation and combustion of the volatile portion of the fuel; and third, the combustion of the remaining or carbonaceous portions of the fuel. After the hydrocarbons have been driven off and more or less consumed, the remaining portion of the solid matter is composed mainly of carbon and ash. It is comparatively simple to secure complete combustion at this stage, so that the solution of the smoke problem deals largely with the combustion of the products evolved in the second stage of combustion. Therefore, the smokeless combustion of bituminous coal depends upon the construction and operation of furnaces in such a manner that the volatile products evolved in the second stage of combustion, are completely consumed before they strike any cooling surfaces which will reduce their temperature below the kindling point. Briefly stated the principles involved to secure these results are:

(a) Air in sufficient quantities for complete combustion must be admitted at the proper time.

(b) The air must be thoroughly mixed with the gaseous portion of the fuel.

(c) The temperature of the gases must be maintained above their kindling point until the chemical process known as combustion is complete.

Pittsburgh's Industries.

The nature of the industries in which any city is engaged depends largely upon the natural advantages of the district in which it is located. The fact that iron and coal were so accessible determined the lines of industrial development in Pittsburgh. Of the two, coal has been demonstrated to be the more valuable. As some one has put it, "Coal is the rock upon which Pittsburgh is built."

While the first industries of the city did not depend upon natural advantages, it was not long before enterprising Pittsburghers began to take coal from the hills of the District to use in furnishing power for their manufactories. The accessibility of iron ore, together with

this coal determined the industrial development of the District. As early as 1792, a blast furnace was built in Shady Side. While pig iron was not produced in the city until about 1850, in twenty years' time the Pittsburgh District had surpassed all other iron producing districts in the country. When steel came to supersede puddling iron, Pittsburgh naturally became the center of the steel industry.

In 1850, when the city had a population of 46,606 there were thirteen rolling mills and thirty large foundries, which, together with cotton and glass factories, consumed about 12,000,000 bushels of coal. It was about this time that the city received the title "The Iron City" and shortly afterwards "The Smoky City."

The census report for 1910 shows that the industries which use ore and metal as the principal materials, and accordingly great quantities of coal, as blast furnaces, steel works, rolling mills, foundries and machine shops, formed more than 50 per cent. of the total value of all manufactured products for the city proper. The city was given seventh rank in the value of manufactured products in the census of 1910. The statistics for the Pittsburgh Industrial District showed that it ranked fourth. In 1909, the Pittsburgh District produced 11 per cent. of the world's output of pig iron; 30 per cent. of the steel manufactured in the country; 50 per cent. of the country's steel cars; and 66 per cent. of the country's glass. In the city in 1909 there were 307,666 primary horsepower employed in manufacturing alone, of this, 227,231 or 73.9 per cent. was assigned to the manufactory of electrical machinery and apparatus, foundry and machine shop products, iron and steel blast furnaces, iron and steel works, and rolling mills. Of the total capital invested in manufactories, 95.5 per cent. was invested in these industries and they account for 60.9 per cent. of the total expenditure for fuel and rent of power. In the District, the above mentioned industries, required 80.7 per cent. of the total primary horsepower utilized in manufactory.

THE COAL CONSUMPTION OF THE DISTRICT.

Coal is the general source of power for all manufacturing purposes in the Pittsburgh District and is applied either directly or indirectly to metallurgical processes as a source of heat in carrying out the various operations. It is almost universally used for heating where heating is done on a large scale, as in office buildings, hotels, store buildings and central heating plants. In some instances it is used for heating dwellings, but is not used extensively for other domestic purposes. The part consumed for all domestic purposes is negligible when compared to the amount used in power generation and for metallurgical purposes.

While coal was mined in Pittsburgh as early as 1760 it was not used for domestic purposes until 1780, for firewood was plentiful, cheaper and cleaner than coal. As was stated in "The History of the Smoke Nuisance," the consumption of coal had reached 3,000,000 tons in 1884 when natural gas was discovered. This consumption fell to about 1,000,000 tons until 1890 when it began to increase again.

The only figures that are available on the coal consumption of the city of Pittsburgh are those furnished by Mr. J. M. Searle, the Chief Smoke Inspector of Pittsburgh. Mr. Searle's figures show that the coal consumption of the city for 1912 to be 5,606,416 tons. The consumption of coal in the Pittsburgh District for 1912 amounted to 17,721,783 tons. [1] This makes the District the largest consumer of bituminous coal in the world. The District is not only the largest consumer of bituminous coal, but when to the coal consumption is added some 5,000,000 tons of coke and the gas consumption for 1912 equivalent to over 3,000,000 tons of bituminous coal, the District becomes the greater user of fuel in the world.

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1 United States Geological Survey—"The Production of Coal in 1912," by Edward W. Parker.

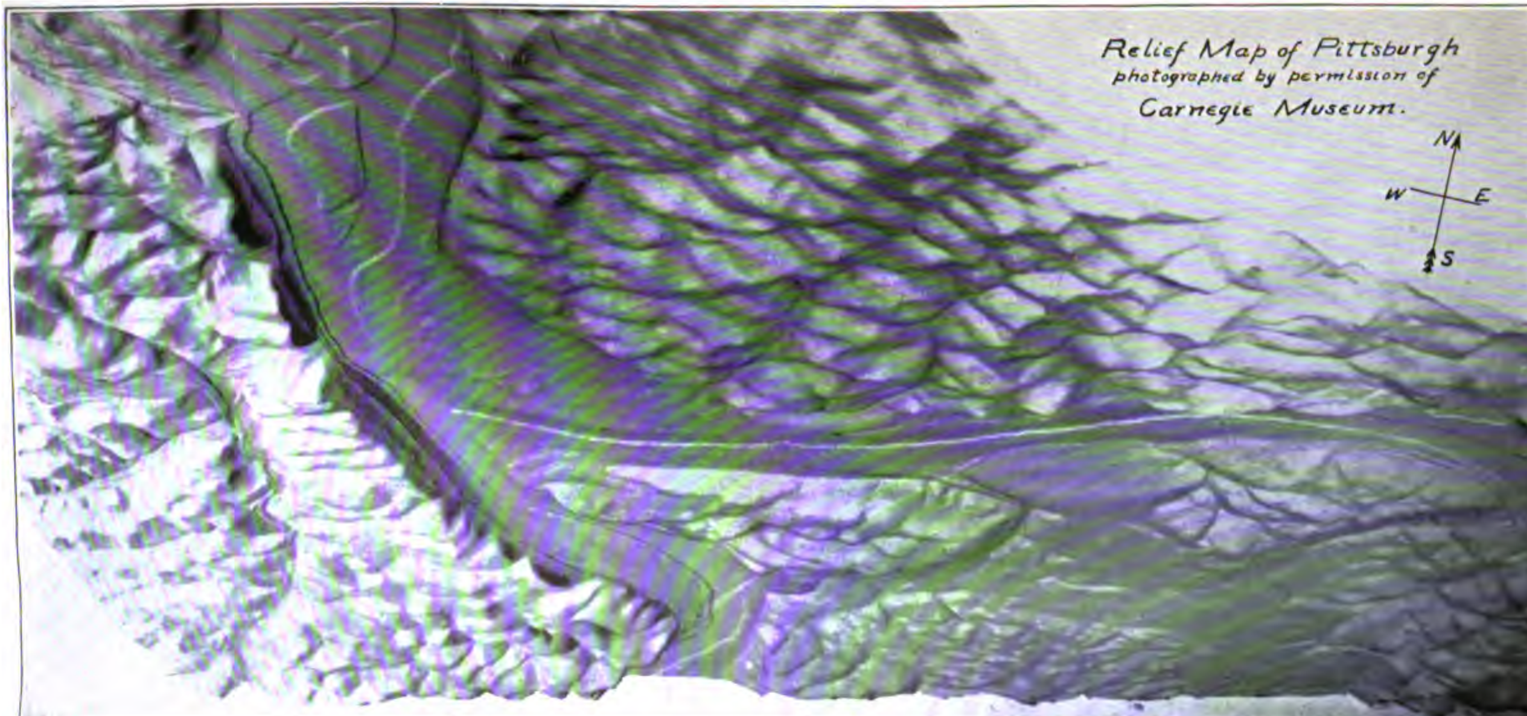

Figure 3—Relief map of Pittsburgh. (White line across middle of page represents the Allegheny River. The light colored parts indicate elevations).

Topography of the Pittsburgh District.

Pittsburgh is located on the point of land where the Allegheny and Monongahela Rivers join to form the Ohio, as is shown in Figure 1. The city of Pittsburgh includes within its limits 41.4 square miles, and, what is known as the Pittsburgh District, comprises an area of 634.2 square miles. The city and district are situated among the foothills of the Allegheny Mountains, and the country is, in general, rough and irregular in its topography, as may be seen from the "Relief Map," Figure 3. This map shows that the hills vary greatly in height and steepness. In a number of instances, within the city, the hills are so steep that they have to be ascended by inclines. This is particularly true of the South Side where the high hills approach the Ohio and Monongahela Rivers so closely as to allow scarcely room for the construction of public highways and railroad beds.

Figures 4, 5, 6, 7, 8 and 9 show photographs taken on the South Side, not far from the top of the hillside, opposite the "Point" of the city. Photographs 4, 6 and 8 were taken on the Fourth of July when very few mills and factories were in operation. The day was exceptionally clear and the sky was, at times, almost cloudless. They give an idea of the condition that could prevail in Pittsburgh even with the mills and factories in operation, provided the proper care was taken in burning coal. Photographs 5, 7 and 9 were taken from the same point on October 8th, between the hours of 12 M. and 3 P. M. The wind was coming from the Northwest and was traveling at the rate of twenty miles an hour. The day was not a foggy one, but, as can be seen from the pictures, was very smoky.

Figure 4 is a view down the Ohio River and shows Brunots Island in the center of the background. The low sloping land upon which the old city of Allegheny is located is seen on the right and the steep hills on the South Side, on the foreground and left. Figure 6 com-

bined with Figure 4 gives almost a panoramic view of the North Side.

Figure 8 shows a view of the "Point" at the junction of the Allegheny and Monongahela Rivers with the Ohio. Again the steep sides of the hills on the South Side are shown. In this picture the waters of the Monongahela are very muddy due to the recent rains along its course. The photographs represented by Figures 10, 12 and 14 were taken from the top of the Oliver Buliding on the same day as Figures 4, 6 and 8. Photographs shown in Figures 11, 13 and 15 were taken on the same day as Figures 5, 7 and 9, and show the smoky condition of the city.

Figures 10 and 12 show the Allegheny River as far up as Herr's Island. In Figure 12, the Pennsylvania Railroad Station is represented just above the center of the picture and just back of it is seen one of the inclines. Figure 14 shows a view of the city looking southeast from the Oliver Building. The picture takes in what is known as the "Hill District." Part of the work in the "Hump Cut" in seen in the foreground. Figures 4 to 14 taken together with the "Relief Map," Figure 3, show, in general, the roughness and irregularity of the land upon which the city is located.

Figure 16 represents the Pittsburgh Flood Commission Map from its Survey, July to October, 1909, and gives the location of the steel mills and factories along both banks of the rivers of this District. It shows how the city, especially the business district, is closed in by mills and factories.

THE WIND DIRECTION AND THE SMOKE NUISANCE.

The effect of wind direction upon the prevalence of smoke in different parts of the city may be traced in the following manner: (For prevailing winds see Appendix 11).

(1) North Winds: The smoke from the north side of the Allegheny River combines with the greater volume from the mills and factories on the South Side; and for a

Contrast Views of Pittsburgh.

Figure 4—View down the Ohio River when the city was free from smoke. Photo by H. C. Anderson

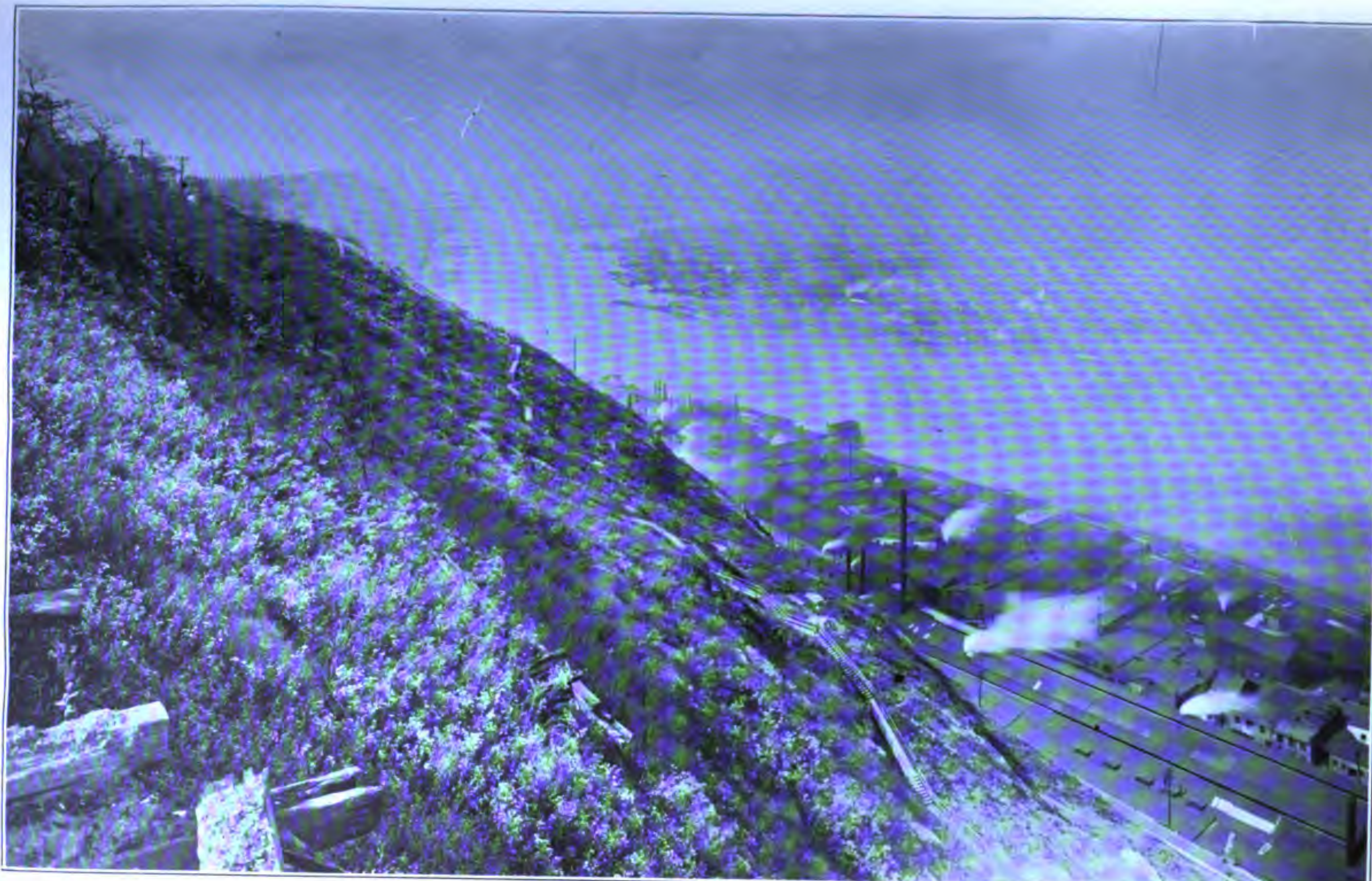

Figure 5—Same view as in Figure 4 on a smoky day.

Photo by H. C. Anderson

Figure 6—View of North Side when the city was free from smoke.

Photo by H. C. Anderson

Figure 7—Same view as in Figure 6 on a smoky day.

Photo by H. C. Anderson

Figure 8—View of the "Downtown Section" when the city was free from smoke. Photo by H. C. Anderson

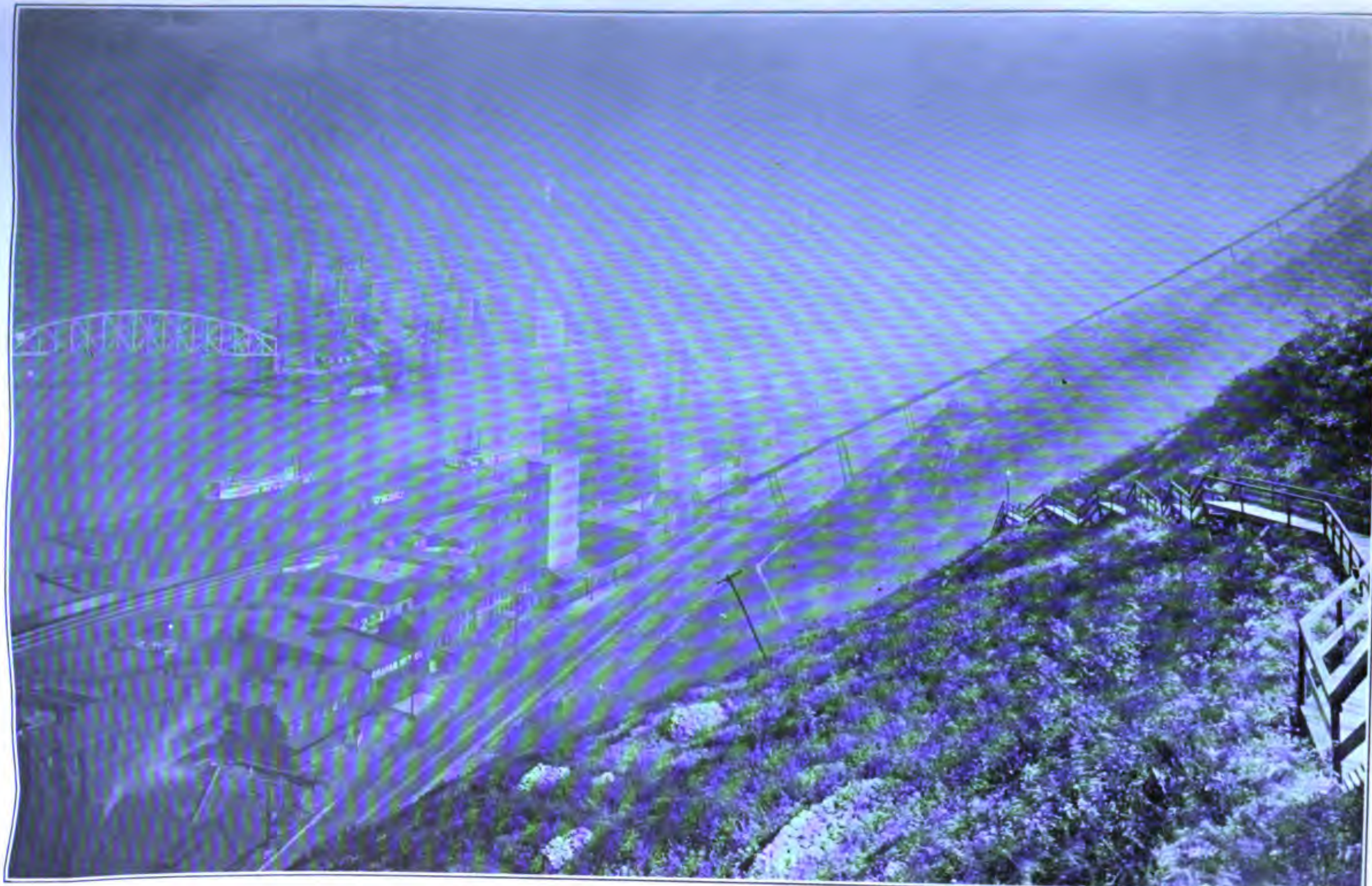

Figure 9—Same view as in Figure 8 on a smoky day.

Photo by H. C. Anderson

Figure 10—View up the Allegheny River when the city was free from smoke. Photo by H. C. Anderson

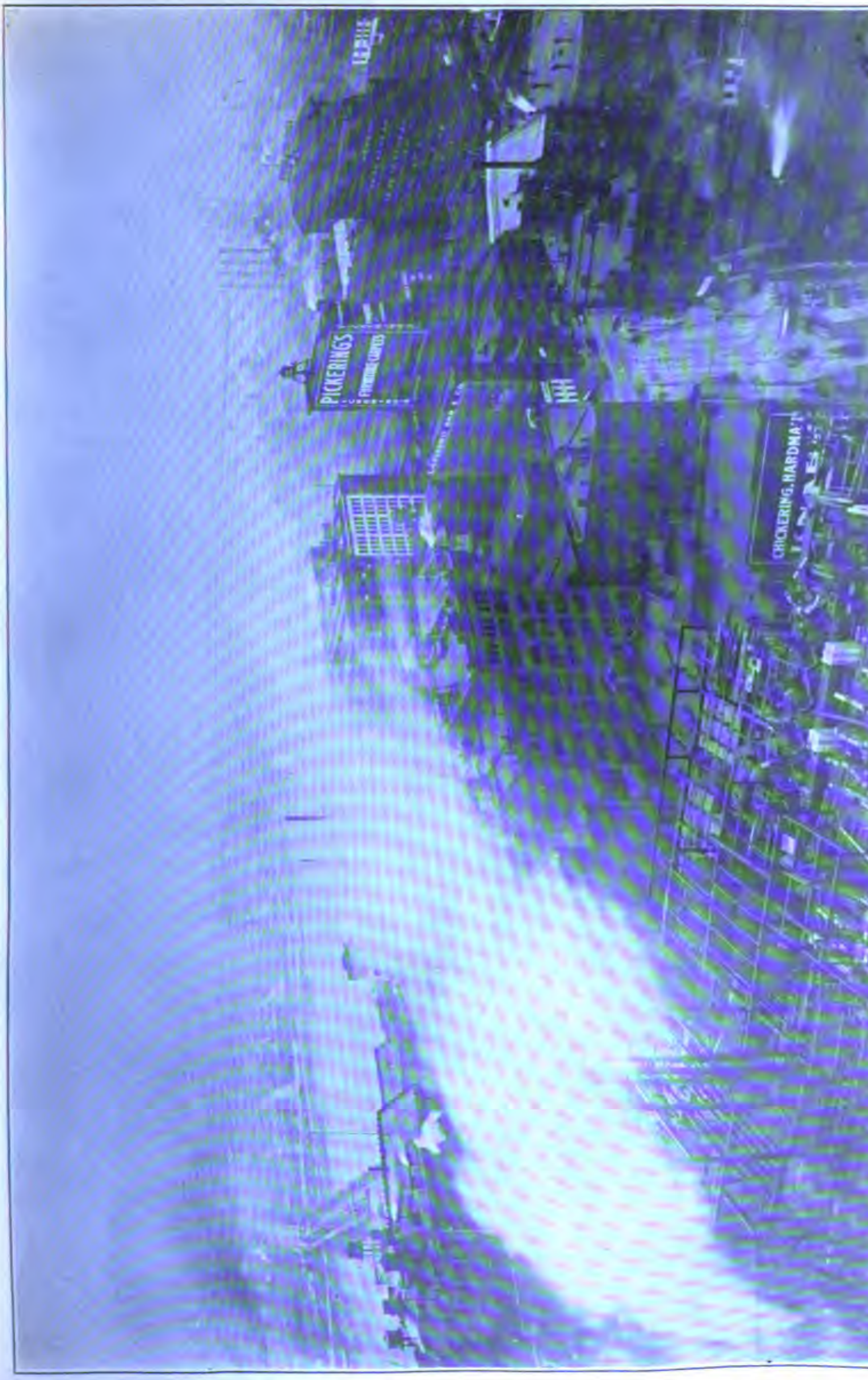
PICKERINGS

Figure 12—View in direction of Pennsylvania Station when the city was free from smoke.

Photo by H. C. Anderson

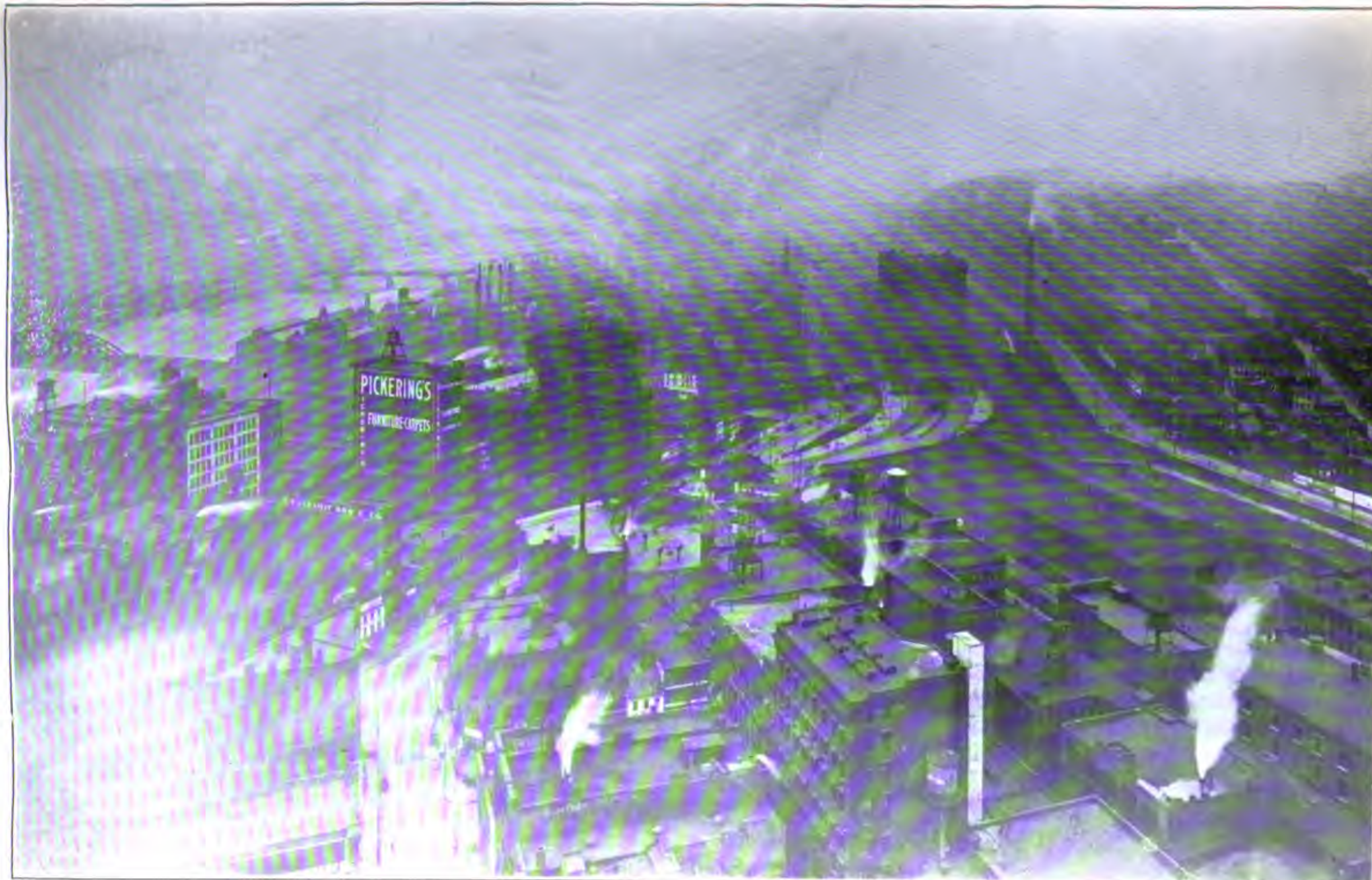

Figure 13—Same view as in Figure 12 on a smoky day.

Photo by H. C. Anderson

Figure 14—View east across the city when it was free from smoke.

Photo by H. C. Anderson

Figure 15—Same view as in Figure 14 on a smoky day.

Photo by H. C. Anderson

distance of almost four miles east of the "Point" the business, as well as the park and residential sections of the city, are subject to its evil effects.

A glance at Figures 9 and 13 will show that the business district as far east as the Pennsylvania Railroad Station receives this smoke at low levels, especially when the wind is high. At such times apart from the additional clouding effect of fogs, the streets of the lower parts of the city afford avenues for the passage of the smoke southward and due to the smoke eddies which form, there is no possible means of preventing the smoke, ashes, etc., from penetrating the stores, office buildings, hotels, theaters, etc.

When the North Wind has a low velocity approaching a calm, there is a greater tendency for the smoke cloud from these same sources to rise to higher elevations, especially the lighter portions of it across the city. The heavier constituents of this smoke cloud, however, such as ashes and ore dust, settle to the ground or on their final resting places within a short distance from the localities where they were produced.

Between these two extremes of wind velocities, the city's life and activities must certainly experience the ill effect of the impurities in the air and simultaneously there are losses along many economic lines. During the prevalence of the North Winds, that portion of the city east of the Pennsylvania Railroad Station has a deflecting wall in the high sloping hill sides on the south bank of the Allegheny River.

The general effect is that the smoke clouds are deflected on these more or less sloping hill sides, and are driven into higher elevations, above the buildings and thus they are carried in sheets high over our heads across the Oakland, Schenley Park and Squirrel Hill Sections of the city.

(2) Northwest Winds: These bring the smoke from the mills and factories along the Ohio River (See Figure 16) and give the business section of the city, perhaps its most complete deluge of smoke, ashes, etc. Even without

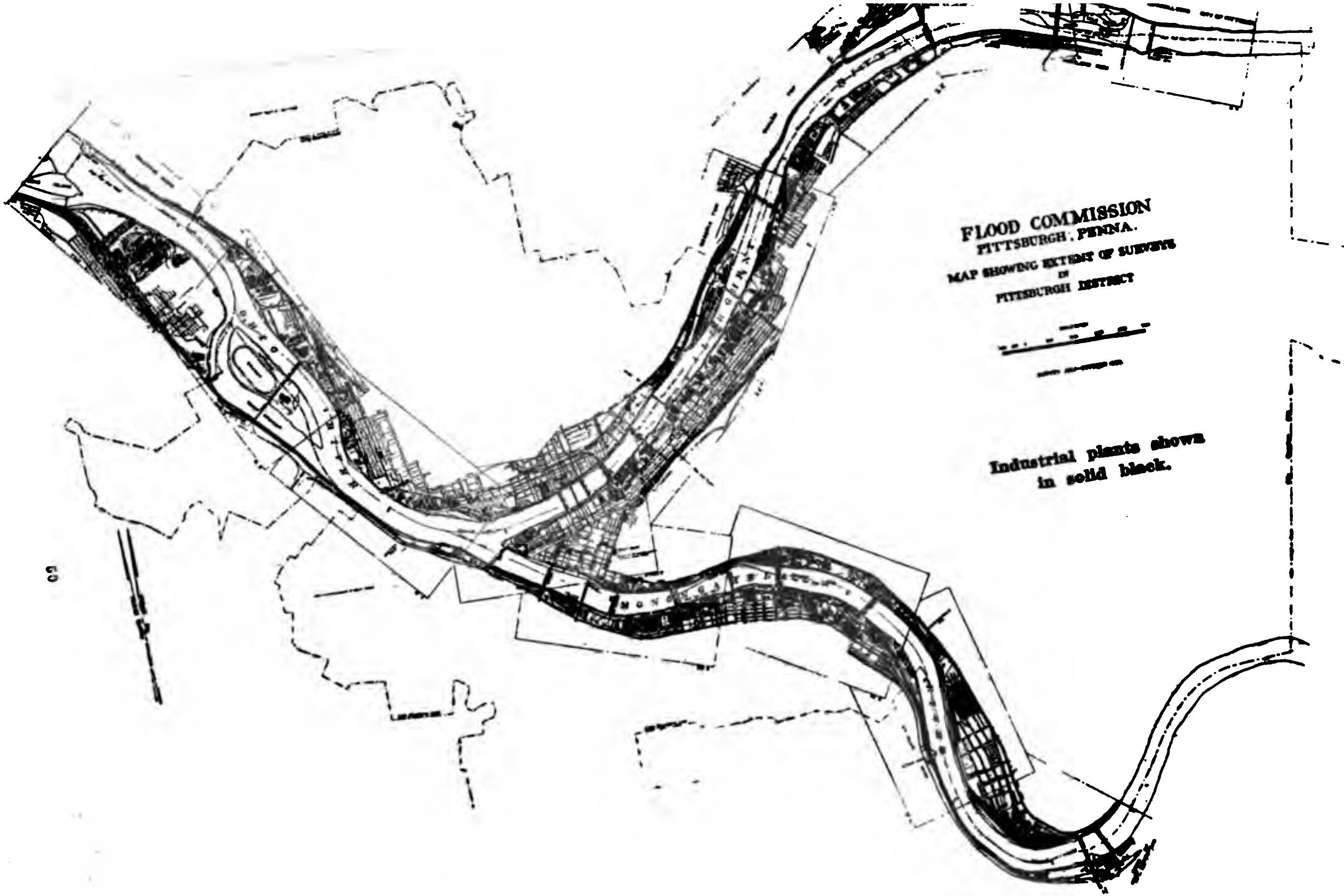

Figure 16—Shows how industrial plants line the river banks.

the existence of fogs, it is quite commonly the case that the stores, office and other buildings have to be illuminated throughout the day. What has been said as to the penetration of the smoke cloud under North Winds, is considerably magnified under the Northwest Winds. It is likewise true that the residential and park districts receive their share of the smoke from the mills along the Ohio River in addition to that already outlined under the North Winds.

(3) West Winds: During the existence of Westerly Winds, the business section of the city is as free from smoke as it can possibly be, under existing conditions, the only sources of smoke being a number of small mills and factories on the South Side, and directly west of the "Point," also the few mills and factories scattered throughout this part of the city itself.

It is only necessary to carefully examine the Flood Commission Map, Figure 16, to realize the truth of these statements. There is a narrow section of the city which is in the direct path of the West Winds which have already swept over the business portion of the city. This part of the city is located on the high and sloping background, as seen in Figures 8, 12 and 14, and due to the high hill sides to the east and right of the Pennsylvania Railroad Station, and on the south side of the Allegheny River, the smoke is somewhat deflected, and tends to be driven up the Allegheny Valley, thence to spread over the residential and Highland Park sections of the District.

At the same time the smoke from the mills and factories along the Monongahela River is carried up the river valley for a short distance (on account of the high hills on the South Side), and then spreads eastward over the residential and park districts.

(4) Southwest Winds: When the Southwest Winds are blowing, the smoke from the mills and factories at McKees Rocks and also those along the north bank of the Ohio River is driven across the North Side, or the old city of Allegheny, and thence spreads over Reserve, Shaler and other townships in its course.

From the mills along the Allegheny River, up as far as Sharpsburg, the smoke generally follows the course of the river and does not spread appreciably for a distance of nearly five or six miles from the "Point." At the same time the business portion of the city suffers very little more than it does due to West Winds.

The smoke clouds, due to the industries along the Monongahela River, are carried by these winds up and over the sloping hill sides on its north bank as seen in Figures 9 and 15, and spreads over the park and residential portions of the districts shown in Figure 15.

For winds in any other directions than those discussed, a reference to the pictures will enable any one to determine with a fair degree of reliability the distribution of smoke in the city.

From the discussion thus far presented, and by the aid of maps and pictures in considering the topography of the Pittsburgh District, it will be realized that there is truth in the statement that "the non-production of smoke is the only solution of Pittsburgh's smoke problem."

Part IV.

The Sources of Smoke in the City of Pittsburgh and the Pittsburgh District.

The smoke in the city of Pittsburgh comes from many sources, both within the city limits and from the outlying districts. The smoke from the surrounding territory is mainly from the large manufacturing plants which border on the city. The smoke within the city limits may be traced (1) to the business section, (2) to the manufacturing plants, (3) to special furnaces, (4) to the railroads, (5) to steamboats, (6) to the residential portion, and (7) to miscellaneous services. The condition under which smoke is made at each source and remedies will be discussed under special headings.

THE BUSINESS SECTION OF THE CITY.

There is probably no portion of the city in which smoke causes more inconveniences and loss, besides affecting directly so many people, as does that made or discharged within the business section or its immediate vicinity. The smoke made in the business portion itself comes mainly from some of the large office buildings equipped with their own plants for furnishing power and heat, from various stores similarly equipped, and from buildings furnishing heat alone. A number of large office buildings have in operation such heating and power installations that only little smoke can be observed issuing from their stacks. Such instances are evidence of what can be done, in practically all cases, when application is made of well known devices, the purpose of which is to avoid the production of smoke. There are relatively few small manufacturing plants in the business portion of the city, but, those that are so located, as well as the

small office buildings, are usually persistent smokers, especially during the winter months. The smoke discharged from these smaller buildings, stores and plants is very offensive in that it is usually discharged at low levels and is carried directly into the windows of the buildings, which surround these plants, causing inconveniences and loss to the occupants of the offices in these buildings, and rapid deterioration of furnishings. All pedestrians are subject, likewise to the evils of the smoke and soot from these stacks.

The reasons for smoke from these plants is fundamentally due to lack of care in design and construction of the installations, and in a large number of instances the operation is also very much at fault. The plants, for the most part, are located in the basements or sub-basements of these buildings. In some instances the light is very poor and surrounding conditions are not such as to encourage the operators to exert their best efforts. Head room is usually very much restricted, necessitating construction of boiler furnaces with small combustion chambers, and, the floor space, in many instances, is only large enough to allow the operator to fire his furnaces. Because of these conditions any disposition to install furnaces with extension fronts, and thereby increase the size of the combustion space, cannot be considered. Tube or heating surfaces are usually exposed directly to the fire, except where the horizontally baffled water tube boiler is used—which usually offers a fire tiled roof over the furnace. Boilers are usually set very closely together, allowing practically no space for dusting the tubes of vertically baffled water tube boilers, and no provision is made for having access to stokers and furnaces for making repairs.

In most cases the stacks are very high, yet the draft is almost universally poor. This is due to the tortious manner in which the breechings are usually installed, involving a large number of short sharp turns and bends, each one of which decreases the draft. Because the quarters are cramped there is usually no space provided

for coal storage, and the operators are dependent on daily deliveries for their supply of fuel, with the result that they are at times required to use fuel which is very much inferior in quality. The difficulty of handling poor fuel on this type of installation, without the emission of smoke, can readily be realized.

It is in plants of this type that the need of official approval of all plans for the installations of boilers and furnaces is most forcibly demonstrated. One very fortunate feature, however, is disclosed in examination of these plants. In practically all cases, the installations are of such size that they can easily carry loads without being forced.

In most of the smaller plants, the installations are hand-fired and are of such construction that the high volatile grades of bituminous coal cannot, without very careful operation, be burned without the production, at each firing, of large quantities of black smoke. Furthermore, the installation is usually of such size that the owner often feels that considerable care in operation is not warranted, and the coal is fired in large quantities and at irregular intervals by low class labor.

The underfeed stoker has lent itself admirably to the remedying of just such conditions as these, in that it burns its fuel with a short flame, therefore, requiring minimum sized combustion chambers to obtain smokeless combustion. Especially is this true at low ratings, also, only enough draft is required to carry off the products of combustion—as the air required to burn the fuel is supplied under pressure by a fan to the fuel bed. It would be unwise to state that this type of stoker would cure any or all of the existing evils, as each plant has its own stated set of conditions, which need to be thoroughly studied before any remedy can be applied.

All plans and specifications for new or alterations in old installations should be prepared by competent experts, so as to enable the operator to keep the smoke emitted by his installation within the ordinance, and obtain good efficiencies. All hand-fired installations of size

over 300 horsepower should be abolished, stokers installed, and the furnaces redesigned, so that they can be operated efficiently and without the production of smoke. When neither of these remedies suffice, it may become necessary to purchase power and use the plant for heating purposes alone—fired either with gas, some low volatile coal, or coke.

A considerable portion of the smoke could be eliminated in the business, as well as residential sections of the city, by the establishment of central heating plants, which would furnish the smaller buildings with heat and power. There are in operation, in the city, several centralized heating plants which supply the surrounding buildings with heat and power. These plants, for the most part, operate very successfully from a standpoint of eliminating smoke.

Manufacturing Plants.

Under manufacturing plants are comprised all manufacturing plants not included in the business section, as well as warehouses, breweries, factories, mills, and electrical and other power plants furnishing power for various purposes. The smoke made by these plants constitutes the largest portion made in the District. It inconveniences and affects every portion of the city whether business or residential. These mills, factories and plants are so located that they form practically a chain about the entire city. This fact may be seen from the Flood Commission Map, Figure 16. Some of these plants come within one or two blocks of being included in the area bounded by the business section. A large number of iron and steel mills and other factories are clustered in lower Allegheny, close to the "Point" of the city, and they produce enormous quantities of black smoke and discharge it at low levels. These mills are within a radius of two miles from the business portion of the city, and because the direction of the prevailing winds being northwest this smoke is generally carried directly up the Ohio valley and into the city. Data for the direction of the wind, and

its velocity, for the years 1911 and 1912, is given under "Prevailing Winds," Appendix I.

The universal fuel used in these plants, because of the low cost and abundant supply, is the high volatile bituminous coal of the District. The general rule seems to be that the nearer these plants are to the center of the city, the smokier is their method of operation. This is the result of the antiquated type of equipment, and methods of installing and operating the same. These plants consist for the most part, of the old style water tube or fire tube boilers operating at moderate pressures, and are in a great many instances hand-fired. The boilers are usually set close to the grates, the heating surface is exposed directly to the action of the flames, and all provision for efficient and smokeless operation completely ignored. In some of the smaller plants, the boiler room is placed in one corner of the plant, with space so restricted that it is difficult for one to walk about, to say nothing about providing space enough to use the tools usually required when cleaning the fire. The breechings and the connections are usually long and tortuous, and not accessible, or are built into a dividing wall of the building. Breechings have been encountered where three sharp right angle bends have been used in a run of fifteen feet, resulting in a decrease of draft of 0.60 inches of water in this distance. Working conditions for the most part are poor. Dark and dirty boiler rooms are the rule rather than the exception, and in some instances, the fuel, which is dry and dusty, is charged directly from the car to the boiler room floor, and from here it is charged to the furnace by hand. In some instances, during the winter months, the boiler rooms are heated by open coal fires discharging smoke and grime directly into the boiler room. This results in making working conditions unpleasant, and decreasing the efficiency of operation.

Considering typical conditions which hold in many plants, mills and factories, as regards poor boiler settings, improperly installed stokers, the class of firemen which is usually to be found operating these plants, and the un-

satisfactory working conditions in furnace and boiler rooms, little progress will be made toward smoke elimination until the authorities in control of these plants stand ready to improve the above conditions.

From data obtained at a small number of plants, representing the average operating conditions of the District, there seems to be justification for the statement that the average boiler efficiency, in daily operation, of the boilers of this District is from 15 to 25 per cent. lower than what it should be. The data consisted of analyses of flue gases, observations on temperatures of flue gases and losses to the ash pit. It was also found that by increasing the care in operation, and properly placing the furnace auxiliaries, which would aid in smoke abatement, the fuel consumption might easily be decreased from one-half to three-fourths pound per boiler horsepower developed. It would, therefore, appear that it would not be unreasonable to expect at least a 30 per cent. decrease in the amount of fuel used, provided the proper changes and additions were made. In a majority of the cases in mind, however, a greater return than this would undoubtedly result. It is to be expected that the manufacturer naturally hesitates to remedy such conditions as these, unless there is some promise of a remunerative return on the investment.

Attempts at smoke abatement in the District have not been attended, in a majority of cases, with the success that should accompany such efforts, mainly, due to faults in the original design, or maintenance of old and inefficient operating methods. For instance, in one case an attempt was made at smoke abatement by changing baffles and placing firebrick promiscuously about in the combustion chamber, without any regard to its effect on the draft or efficiency of operation of the boilers. Changes were also made in the stoker, by which the air space in the grates was very much restricted, with the result that the coal consumption per square foot of grate surface was very much decreased with an accompanying decrease in the boiler capacity. The result of these efforts showed

the following conditions: Draft in the furnace 0.10 inches of water, and in the breeching near the stack (two boilers to one stack), 0.90 inches of water; temperature of the gases leaving the boiler 675° Fahrenheit; and the emission of dense clouds of smoke. The refuse from the ash pit at this plant also showed that a liberal percentage of fuel was carried away in the refuse.

With a vertically baffled water tube boiler, where the gases are usually required to change their direction of flow three times before entering the breeching, the loss in draft from the breeching to the furnace should not be more than 0.4 inches of water instead of 0.8, as is shown by observation on this setting. The temperature of the escaping gases is abnormally high, 150° higher than it should be if the furnace was operating properly. Considering the fact that the fire, in the above mentioned instance, was not in good condition when this reading was taken, that the fuel bed was full of holes, and, that there was a large excess of air, the heat loss up the stack was probably nearer 35 per cent. than 12 per cent. This latter figure represents more nearly the best operating practice.

In one instance, of which particular notice was taken, the settings were properly installed, and under careful management the elimination of smoke was accomplished. The methods of firing in this plant are very lax and inefficient, and no attempt is made to remedy them in connection with this new installation. Although this plant, in its present condition, is an improvement on the former one, it smokes badly at times, due to improper handling. Efforts to obtain smoke abatement by such methods, as just mentioned, are very much to be deplored, as the results accomplished are the direct reverse of what they should be. Two very important factors, both of which aim at efficient and smokeless operation of plants are emphasized in these new installations. They are: First, the importance of proper installation and construction; and second, the need of exercising care and having constant intelligent supervision of the operations in the boiler room. The large number of recording and other instruments now on the

market make possible the obtaining of accurate records of the various elements which effect efficient and smokeless operation. When special equipment is installed the fact is usually overlooked, however, that considerable care must be exercised in operation, or the results obtained will not be any improvement upon former conditions.

It is of the utmost importance, in the remodeling of existing installation and the construction of new ones, that the equipment be so selected, designed and installed, that it will operate at its maximum efficiency without the production of smoke, and with the exercise of minimum care on the part of the attendant. It is unreasonable to expect any high degree of intelligence to be exercised by men of the type usually found in the firerooms of plants of this District. Neither should the fireman be expected to work constantly at the furnace, poking, slicing and firing, especially when a mechanical stoker is supplied, which, in a measure should relieve him of some of these duties. Where the mechanical stoker is installed, the fireman is called upon to care for a larger number of furnaces than when hand-firing methods are used. This results in a decrease of the amount of attention that each furnace will receive. Any mechanical stoker in which the fuel bed must be continually hooked and poked in order to maintain steam pressure, is not much improvement over hand-firing.

In a majority of the plants of the District, firing methods are very lax, firing is poorly done, and intelligent supervision of operating conditions lacking. Especially is this the case with the smaller manufacturing and power plants. In a majority of cases no attempts are made to instruct firemen as to the proper manner of handling fires. New men are usually placed at work without proper instruction, and they are left to pick up what information they can from their associates in the fireroom. There is but one outcome of such a condition, and that is that inefficient and laborious methods of handling the furnaces are acquired and clung to most tenaciously. The practice now in vogue in plants where high efficiencies and smoke-

less operations are obtained, is to train men to become firemen by permitting them to perform other duties about the fireroom for a reasonable amount of time until they have become familiar with the requirements. These duties consist in assisting the firemen, observing the handling of the furnaces in the proper manner, and the performance of other duties which will acquaint them with the proper methods of furnace operation. Thus by the time they are called upon to serve as firemen they are duly qualified to do so. This plan is much to be preferred over the haphazard method of making any one a fireman who has nothing more in his favor than physical qualifications for the work. Some of the foreign cities, in which great advancement has been made toward smoke elimination, require firemen to be duly qualified and pass an examination before they are given charge of boiler furnaces. These cities maintain instructors and a school where firemen are given boilers to fire, and are instructed in the proper method of handling stokers and furnaces.

Some of the more important factors, a consideration of which will enable the manufacturer to obtain efficient and smokeless operation of his plants, are: Remodeling along proper lines the poorly constructed installations, and replacing old and worn out installations with modern apparatus is highly important; centralized stations of ample size should replace the numerous, small and scattered boiler plants; and hand-fired furnaces should be eliminated in plants of more than 300 horsepower capacity. In addition to these it is highly important that the equipment be maintained at its maximum operating efficiency at all times, that careful and scientific supervision of operating methods be provided, and, that maximum efficiency from the operating force might be secured, working conditions should be of the highest order obtainable under existing circumstances.

Special Furnaces.

The term "Special Furnaces" includes all furnaces for metallurgical processes, such as puddling, heating and re-

heating furnaces and soaking pits; furnaces for burning brick, terra cotta and similar purposes and any other class of special furnaces using bituminous coal as a fuel.

The most important of the special furnaces of the District, both regarding smoke production and number, are the metallurgical furnaces. (See Figure 17.) The furnaces of this type which emit smoke in carrying out the various operations of their processes are:

1. Puddling furnaces used for the manufacture of wrought iron.

2. Heating or reheating furnaces in which the iron or steel is placed to be thoroughly heated after it has once been forged or rolled into rough shapes (when the metal is thoroughly heated in these furnaces it is removed to be rolled into final shapes for use).

3. Hot air furnaces in which either iron or steel is melted for making castings of a better grade, and where considerable control must be exercised over the composition and homogeneity of the final product.

4. Soaking pits, where the ingots, which are the products of either the Bessemer or Open Hearth Processes for making steel, are thoroughly heated for finishing into final shapes for the market. To make these ingots, the metal produced by either of the above processes, is cast in an iron form in which it is allowed to cool until it has attained a certain amount of rigidity. Then the ingot and form are taken to a stripping machine where the form is removed and the ingot is then placed in the soaking pit to be thoroughly and evenly heated before being supplied to the finishing rolls. In all of the processes except the soaking pits, coal is chiefly used, but in the former, either natural or producer gas are the fuels.

In the types of metallurgical furnaces now to be discussed no smoke is made, but considerable dust, and large quantities of highly colored fumes are given off. The blast furnace, which is used for the manufacture of pig iron, employs coke as the fuel, and limestone is added to carry off the various impurities of the ore and fuel in the form of slag. The main inconvenience to the surrounding com-

Figure 17.—Smoky condition in neighborhood of metallurgical furnaces.

munity due to this process is caused from the ore and limestone dust carried out from the stoves in which the air for the operation is heated. To heat these stoves the gas from the furnace is used.

In the Bessemer Process for making steel, the molten pig iron from the blast furnace is charged into a converter; the charge is changed to steel by blowing air through the molten mass and simultaneously removing the impurities. The process is fundamentally as follows: The impurities of the iron combine with the oxygen of the air and furnish the necessary heat to keep the charge of pig iron molten and allow its transformation into steel. It is during the early stages of this process that there is an emission of heavy fumes, which are discharged at low levels.

In the Open Hearth Process for making steel, the molten pig iron from the blast furnace is charged into a type of Seimens Regenerative furnace where the charge is melted down and changed to steel. Either natural or producer gas is the fuel used to furnish the heat necessary. The impurities of the iron are flushed off in the form of slag. In the early stages of this process, fumes are emitted, usually of a yellowish color. These furnaces are usually provided with tall stacks so that the dust and gases are discharged at a considerable height above the surrounding territory. The foundry cupola is very much used to melt the pig iron for castings where the grade of the finished product need not be of such high quality and uniformity as that produced by the hot air furnace. This type of furnace uses coke as a fuel and limestone as a flux to remove impurities. No smoke and not a very great amount of fumes are the result of the operation of this process.

Until recently, all puddling and mill heating furnaces were exempt from the Pittsburgh Ordinance regulating the emission of smoke. During one stage of the puddling process, the conditions are unfavorable for smokeless operation, and this fact has always been the basis for the most formidable arguments against smoke abatement. The

puddling furnace is a simple reverberatory furnace fired from one end and having an opening in the side for charging and working the iron. The puddling furnace is usually fired by hand, uses large size bituminous coal, and has inexpensively constructed grate bars.

The Puddling Process is usually divided into four stages in the order in which the various operations are carried out.

In the first stage, the heated furnace after having been charged with pig iron and hammer slag is made as airtight as possible by closing all the doors. During this first stage the fire should be kept as hot as possible and with due care no smoke should be emitted. As soon as the iron has been completely melted this stage is finished.

During the second stage, a maximum heat and oxidizing atmosphere must be maintained in order to aid in removing impurities. On account of the construction of the furnace with ample refractory surface, and because of the intense heat developed, conditions at this stage are ideal for smokeless operation, and such should remain so unless the furnace is very carelessly operated.

The object of the third stage of the process is to bring "on a boil of the metal" in the furnace. To do this the temperature of the furnace is lowered by closing the damper in the stack, and filling the furnace with an atmosphere of smoke. Closing the damper results in the burning of the fuel on the grate with insufficient air and causes smoke. At this stage the process is a smoky one, although with the exercise of care on the part of the operator, and by application of some of the forms of stokers now on the market, the amount of smoke made should be appreciably decreased. It is also claimed that an oxidizing atmosphere during this stage would be detrimental to the quality of the finished product.

In the fourth, and last stage, a welding heat must be used to form the iron into balls, so that it can be conveniently worked under the hammer to be reduced to sizes suitable for reheating and finishing. Here, again the exercise of a moderate amount of care in the operation is

necessary in order to avoid producing smoke. With the increased use of steel, and its replacement of wrought iron, the puddling furnace rapidly gave way to furnaces for the manufacture of the former. It seems, however, that the use of the puddling furnace has decreased about as much as it will for some time to come, and that the problem of eliminating smoke from this source should receive more study than it has in the past.

Heating and reheating furnaces are usually fired with coal and by hand, however, in some cases either producer or natural gas is used. In other cases the mechanical stoker has been very successfully applied to these furnaces. When hand-fired directly with coal, the process is intermittently a smoky one. In cases where the stoker has replaced hand-firing, smokeless operation is obtained and it is claimed that it resulted in an improvement of the quality and an increase in the quantity of the finished product from the same furnace. On account of the decrease in the available supply of natural gas, its use as a fuel as applied to these processes is limited. A discussion of the merits of powdered coal for metallurgical processes will be found under Appendix II.

For hot air furnaces, which are another type of reverberatory furnace, the same statements will apply as were made for the heating and reheating furnaces.

When using coal, stoker firing is much to be preferred over hand-firing with any of the types of furnaces mentioned, for the following reasons: First, excess of air can be decreased to a minimum resulting in less waste of iron due to oxidation; second, a more even and uniform temperature is maintained and the importance of the personal factor decreased; third, a higher temperature and increased life of the furnace are the result of this steady application of heat and the elimination of a periodical admission of large quantities of cold air; and fourth, increasing the intensity of the heat will result in a decrease in the time the metal must remain in the furnace, thus increasing the output.

After the ingot has been stripped, as previously de-

scribed, the metal has become too much cooled to permit of its being sent to the rolls for finishing or rolling into smaller size so that it must first be sent to the soaking pits for treatment. The function of the soaking pit is as the name implies, "to soak an ingot in heat" so that it will have a uniform temperature throughout and that the whole mass of metal shall have attained the same degree of plasticity before it is sent to the rolls to be reduced to various sizes and shapes. From six to ten ingots are placed in one compartment of these soaking pits at each charging. These soaking pits consist of long trenches usually placed below the floor level and are lined with firebrick. They are deep enough so that an ingot can be stood on end and a door or cover slides over the ingot without interference. This cover, which is lined with firebrick, is so constructed that it will slide back and forth on rollers to allow for placing the ingots in the pit. The universal fuel used to heat these pits is gas, either natural or producer, and although gas is used as the fuel, these pits are the source of considerable smoke. They did not until recently, however, come within the scope of the existing ordinance, and, as they represented a very small per cent. of the plants producing smoke, very little study has been made of this phase of the subject.

Furnaces for burning brick and terra cotta are very smoky in their operation, especially during the drying out and baking process of the product. However, at the later stages of the process, when the vitrifying of the product commences, the operations may easily be carried out without the production of smoke. The smoke can only be eliminated at the earlier stages of the process by the use of some other fuel than Pittsburgh coal, or by some method of precipitating the carbon and tarry products of the smoke.

There are in operation in this District a considerable number of ovens for making coke. These ovens smoke almost constantly, although the smoke at any one time is no denser than 60 per cent. black. The elimination of smoke from this course presents no serious difficulties as

Figure 18—Smoke from locomotive in a residence section of Pittsburgh.

the gases leave the ovens at high temperatures and are conveyed by long passages to the stacks where they are discharged. There should be some remuneration resulting from the complete combustion of these gases by performing useful work before they are discharged into the atmosphere, and if such were done, smokeless operation could be obtained.

It is probably only a question of time until these antiquated coke ovens will be replaced by by-product coke ovens, which, while costly to install, are in the long run more profitable than the older forms, and which give no smoke.

RAILROADS.

Second in importance to the smoke problem of the manufacturing plants is that of the railroads. The smoke from railroads is much more objectionable on account of the low levels at which it is discharged and the large amount of cinder and sparks emitted with it. On account of these conditions in the District, the amount of damage done by the smoke from railroads is a higher percentage of the damage by smoke from all sources than the smoke made by railroads is of the total smoke produced. The smoke from locomotives is discharged at roundhouses in the vicinity of terminals, freight and warehouses, manufacturing plants and mills, and is usually trailed after the train over the right of way, and the immediate surroundings. Cinders and sparks are for the most part deposited on the company's own property, but in many instances are carried to some distance from the right of way. (See Figure 18.)

The problem of abating smoke and decreasing the amount of cinder discharge from the stacks of locomotives has been one of the foremost problems confronting railroads for some time. Because of restrictions inherent in the design and operation of locomotives, the problem has been more difficult of solution than that of the stationary plant. In a locomotive the size of the firebox is restricted, and therefore the grate area upon which to consume the

amount of coal to be burned in order to develop the requisite power is very small. In a stationary plant, the size of the grate is limited only by difficulties in construction. With a locomotive the grate cannot be any wider than the gauge of the track will allow, or any longer than the distance a man can throw coal, which is now usually taken to be about 9 feet. In a locomotive, coal must be consumed at from three to six times as rapidly as in stationary plants. This necessitates the use of a powerful draft. To supply this draft, the exhaust steam from the cylinders is discharged directly into the stack. Although it allows a high rate of combustion, this intense draft increases the dirtiness of operation in that it carries large quantities of fine coal, ash, and partly ignited fuel through the flues and discharges them through the stack as sparks and cinder. Especially is this the case with quick burning friable coals, or when fuel containing considerable slack is used without wetting the same.

Firebrick arches are now usually supplied on locomotives over the back end of the firebox. These arches aid materially in maintaining high furnace temperatures, mixing of gases, and in some sense, making the furnace regenerative. Elaborate baffles cannot be applied, or large combustion chambers obtained, as with the stationary plant. This is due to the rough service such as vibration to which the locomotive is subject, and the restricted amount of space available. When using bituminous coal, especially those of high volatile content, the railroads are required to depend on one of several methods for smoke elimination: First, increased care in firing and proper equipment; second, the application of the mechanical stoker to the locomotive; and third, the steam jet.

By all means the most efficient methods of preventing smoke in a locomotive is to have a careful and alert fireman. He is a greater factor in preventing smoke than the coal or equipment of the engine. A careful fireman can take a poorly equipped engine supplied with inferior coal and make less smoke and dirt than a careless fireman with a locomotive equipped with every possible de-

vice and the best coal. When hand-fired, the amount of smoke, sparks and cinder discharged by locomotives depends even more on the care exercised in firing than on the equipment of the engine. The amount of smoke and cinder discharged can be materially decreased by using low volatile, high grade, bituminous coals. Coke has also been supplied for use in locomotives in districts where smoke is especially objectionable.

Two different types of mechanical stokers have been applied to locomotives. The first consisted in placing a device in the locomotive which scattered or sprinkled the coal over the grate. This type caused more smoke than hand-firing, and considerable difficulty was experienced in maintaining an even fire and constant steam pressure. The second method of eliminating smoke was an application of the underfeed principle in feeding the fuel, and better results have been secured than with the first type. A stoker of this type has been designed and placed in operation known as the Crawford Stoker. Quite a number of locomotives now entering the city are equipped with this stoker. With it the fuel is rammed into retorts, placed lengthwise of the firebox. Here the fuel is ignited. It then rolls or falls onto grates at the sides of these retorts and is completely burned. Tests with this stoker show that only brown smoke is emitted in road operation. When the grates are shaken or the fire hooked, smoke will be emitted, yet the period is of not as long a duration as when these same operations are carried out with hand-firing. Observations in a double headed train in road operation, one locomotive hand-fired, the other stoker-fired, showed an average of 60 per cent. black smoke for the former, and 20 per cent. black smoke for the latter. The results obtained from this stoker can hardly be said to have exceeded those attained by skilled hand-fired practice, but will far surpass the average hand-fired practice in economy and smoke elimination.

The almost universal fuel used in locomotives operating in the city is Pittsburgh coal. The utmost care must be exercised in the handling of this fuel in locomotives

in order to keep the smoke and cinder discharged within reasonable limits. This is true because this fuel ignites readily when charged to the furnace and causes very hot fires.

As a result of a very extensive study, the Smoke Inspection Department of Chicago stated: [1] "The experience of the Smoke Department has shown that there are no patented smoke devices which may be applied to locomotives which are successful in preventing smoke. The best equipment that a locomotive may have for this purpose consists of:

First. A strong and efficient steam blower in the base of the smoke stack. This blower pipe should have at least 1¼ inch steam connection and should be so equipped with valves that either the engineer or fireman may use it. This is for the purpose of supplying draft when the locomotive is not running. This blower should always be used when the engine stops and the fire is in such condition that smoke will be made unless there is a strong draft.

Second. A brick arch in the firebox. This arch is for the purpose of giving a high temperature to the firebox and causing the gases to mix well with the air while in that part of the firebox where the temperature is high enough for combustion. Bulletin No. 2 issued by the Smoke Department goes into the question of brick arches in detail.

Third. The fireboxes should be equipped with combustion tubes. These consist of tubes about 2 inches in diameter extending through the water space on each side of the firebox which admit air above the level of the fuel bed. Depending upon the size of the firebox, from five to six tubes of this sort should be placed on each side. A current of air through these tubes is insured by blowing a small jet of steam through them by means of a pipe about ⅛ inch in diameter."

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[1] Report of the Department of Smoke Inspection, City of Chicago, February, 1911.

The topography of the city affects materially the operating conditions of the railroads and complicates the problems of smoke elimination. The various terminals of the railroads are situated not far from the junction of the two rivers and at comparatively low levels. Practically all trains leaving the city and going eastward are required to ascend heavy grades and pull around sharp, or long, sweeping curves. It is necessary to exert a heavy pull from the time a train starts until it has passed beyond the city limits. This necessitates heavy firing and is responsible for a large amount of smoke and cinder. All of the roads leaving the city have their tracks along the base of hills or in valleys between the hills. The contour of the District is such that there is a tendency to pocket the smoke and cinder in the valleys, or deposit them over residential sections immediately overlooking the same. Residents located on the top of the hills suffer heavily from the smoke made by locomotives in the river valleys. In every case where a railroad passes a city park the grades are steep for outgoing trains. This calls for heavy firing, and very often the aid of a pusher locomotive to help freight trains over these grades. It is in these cases that coke has been supplied for fuel, especially in the pusher locomotives. Some coke is used, however, in districts where the smoke is especially objectionable and cannot be eliminated entirely when using coal. The topography of the District, however, is very favorable for smokeless operation of trains entering the city and coming from the East. It is not an unusual thing to note a heavy westbound train entering the city and operating with a clean stack, largely due to its coasting down grade under its own momentum, while a light eastbound train leaving the city may be emitting dense clouds of smoke.

There are operating within the city limits of Pittsburgh, five different Trunk Line Railroads: The Pennsylvania Railroad Company, the Pittsburgh & Lake Erie Railroad, the Baltimore & Ohio Railroad, the Buffalo, Rochester & Pittsburgh Railway, and the Wabash Railroad.

In order to enable us to obtain some idea of the amount of coal burned on locomotives entering or leaving, and passing through the city limits daily, a circular letter was sent to the various companies operating lines entering the city. As a result of this letter the following information was obtained:

	Passenger	Freight	Not Classified
Average number of locomotives entering and leaving the city limits daily,	429	460	107
Probable tons of coal burned while within the city limits	450	830	
Number of tons of coal put on engines in Pittsburgh daily,	1,570	1,325	410
Average number of shifting engines operating within the city limits daily,			63
Probable pounds of coal burned per hour by each locomotive of this class.			600

No data was officially supplied the Investigation as to the number of switching engines using coke, consequently no figures can be given for this fuel in this particular kind of service. The number of different locomotives, and the total number of locomotives entering and leaving the city are not the same, because, when a locomotive entered and left the city more than once daily, each time it entered and left the city it was tabulated as "one locomotive entering and leaving the city." This tabulation is made necessary, as many local passenger trains make several round trips daily, and cover short distances only.

There is burned daily on locomotives, while within the city limits, approximately 1,700 tons of fuel, of which at least 95 per cent. is Pittsburgh bituminous coal. Much of this coal is burned in the locomotives in the round houses while starting up fires preparatory to road runs. At present not many of the locomotives of the District are

equipped with combustion tubes for introducing air over the fire, although most of the locomotives have firebrick arches. To handle this amount of Pittsburgh coal daily on these different locomotives requires the utmost care in operation in order to keep the amount of smoke made within reasonable limits.

Among the worst smoke offenders, and presenting a very difficult problem for solution are the round houses. Some of the larger round houses, when they were installed, were well outside the city limits. However, due to the growth of the city, the residential portions now immediately overlook them and suffer heavily from their smoke and dirt.

There are eight railroad round houses located within the city limits, as follows:

Railroad.	Location.	No. of Stalls.
Pennsylvania	Near Columbus Ave. & Marquis St., Allegheny,	41
Pennsylvania	Twenty-eighth St. & Liberty Ave.,	22
Pennsylvania	Forty-eighth St. & Allegheny River,	9
Pennsylvania	Thirty-second & Carson Sts.,	20
Pennsylvania	McFadden St., Allegheny,	9
B. & O.	Near Melancton & Dyke Sts., Glenwood,	25
B. & O.	Forty-third St. & Allegheny River,	3
B. & O.	Foot of Corey St., Allegheny,	11

The total of eight round houses, located in the city proper, contain one hundred and forty stalls. Located in the District and within a distance of from $4\frac{1}{2}$ to $8\frac{1}{2}$ miles from the city, there are five round houses in active use containing ninety stalls. The fueling of locomotives, the building of new fires, and the cleaning of fires, is necessarily a dirty and objectionable operation at best, and, as this work is usually done at the round house or in its vicinity, the difficulty of eliminating smoke from this source is apparent.

Coke has been used while firing up, and backing the locomotive out of the round house, but on account of the character of the fumes discharged, its use has been discontinued. This was due, largely, to the inability of the men to work in, what was in all probability, a poisonous atmosphere.

In some sections of the country, in order to eliminate the smoke at round houses, the railroads have erected high stacks to which the stack of the locomotive is indirectly connected while being fired up. This high stack or chimney creates the draft for building and maintaining the fire until steam pressure has been raised. In order to eliminate the nuisance from the objectionable particles of the smoke it is customary to conduct the smoke through a washer so as to remove the carbon and tarry particles from the gases before they are conveyed to the chimney and discharged into the air.

The use of combustion tubes in locomotives should aid materially in the elimination of smoke, when starting new fires, and rebuilding old ones after they have been cleaned. This method allows ample air to be introduced over the fire at times of greatest need. The time to get up steam could be reduced and therefore the amount of smoke might be materially decreased when starting new fires, by filling the boiler with hot water as close as possible to 200° F.

Steamboats.

The rich bituminous coal fields of the District have their outlet to the South through Pittsburgh, by way of the Allegheny, Monongahela and Ohio Rivers. Pittsburgh is the natural harbor where the boats which are used for towing the coal to the Southern ports tie up during unfavorable stages of the river. The coal is brought from the mines in barges and pooled at Pittsburgh to be shipped South. The smoke due to this source is chiefly produced by boats handling this coal, making up fleets for shipment, towing and arranging empty barges to be sent back to the mines, and in supplying fuel by barge to the various

Figure 19—Steamboat on the Monongahela River.

industries of the city for power and manufacturing purposes.

Only a small portion of this smoke comes from the boats engaged in passenger and freight traffic. (See Figure 19). This is accounted for by the fact that only a few boats are now engaged in passenger and freight traffic upon the rivers. During unfavorable stages of the river, all passenger and freight traffic is discontinued, this usually occurs in the latter part of the summer and early fall. The boats engaged in shifting tows about the river and supplying local needs for fuel are inveterate smokers. They produce considerable annoyance, inconvenience, and loss to the office buildings situated along the river front, to occupants of these offices, to pedestrians using the bridges connecting Pittsburgh proper with Allegheny and the South Side. In times of high water and favorable stages for coal shipment, the rivers are a scene of very much activity lasting from several days to one or two weeks. These activities consist in the shifting of tows, and the firing up of the large boats, the latter being responsible for the emission of quantities of black smoke.

The equipment of these boats usually consists of old style two-flue, or horizontal return tubular boilers, fired by hand with large size bituminous coal. The shell of the boiler is exposed directly to the action of the flames and the distance from the grate to the shell is very short. The firemen employed on boats represent the poorest class. The enforced periods of idleness and the temporary high wages paid appeals to this type of shiftless individuals. Although the fireboxes are not so much restricted as those of a locomotive, yet there is not enough space available on these boats to install special methods of furnace construction to aid in increasing efficiency and smoke elimination. The present type of installation in use on these boats can only be operated, without the emission of black smoke, by using a high grade low volatile coal, extreme care in firing, and some provision for a secondary air supply at time of firing.

As a majority of the boats on the rivers in this vicinity, and all the boats engaged in towing coal to the Southern ports, are the property of the various coal companies which have their headquarters in the city, it is logical to expect that they would use the high volatile smoky coal of the District. The firemen employed are careless and are picked up regardless of all other qualifications than physical fitness. They have no promotion or better position to look forward to, as do the locomotive firemen. Furthermore, efficiency or smokeless combustion is of little consequence to men of this type, and at the best, most of these so-called firemen are only coal shovelers. Their only aim is to supply enough coal to the furnace to keep up sufficient steam pressure, regardless of the amount of smoke made or the fuel required. The size of fuel fired and proper methods of firing have no significance with them. Especially is this true of the larger tow, passenger and freight boats, the operation of which is entirely dependent upon a favorable stage of the river. The difficulties, however, do not rest entirely with the method of firing. The equipment that these men are compelled to handle cannot possibly be operated without the emission of dense smoke, when fired by hand, even by expert firemen using Pittsburgh bituminous coal.

Very little study has been given to this phase of the subject and until some effort is made in this direction and advice is given to aid in abating this nuisance, the firemen should not be held entirely responsible. Up to the present time no efforts have been made to apply the mechanical stoker to boats of this class. If these conditions were fully recognized in the original design, there should be no reason why certain types of stokers would not lend themselves readily to application on these installations. It would seem that unless a low volatile bituminous coal is used, the solution of this problem must depend upon the stoker. The use of low, volatile bituminous coal, as fuel on the boats, would in itself have a direct tendency to decrease the amount of smoke. Wasteful firing methods would have to be discontinued

when using this more expensive fuel, and any increase in care of firing has a direct bearing on the elimination of smoke.

Residence Section.

Under the "Residence Section" are included apartment houses and all residences using bituminous coal for domentic purposes, or for heating. A comparatively small amount of smoke comes from the apartment houses of the city. Except for the very large apartment houses which furnish their own power, and power to some of the buildings in the neighboring districts, these buildings are equipped with heating plants only, in which natural gas is the fuel used.

In the buildings of this class where power is also furnished, the boilers are usually fired by hand with Pittsburgh coal. In some of these instances, however, mechanical stokers are installed and the operating conditions are usually very good. More care and proper supervision of the original design and lay-out of plants is needed, as installations are quite frequently constructed without much provision for efficient and smokeless combustion. The breechings are often long and tortuous containing many sharp angled bends, or are so located that they are practically inaccessible. The boiler capacity installed is usually ample to carry the required load without forcing. Much care should be exercised in choosing the size of fuel which lends itself to the best operation, as regards a minimum production of smoke. Large size fuel, or screened coal of the smaller sizes entirely free from slack, is generally used. When heat alone is the requirement, and natural gas is not used as fuel, these installations produce much smoke and soot. Boilers used for heating purposes are of the cast iron sectional type, and do not adapt themselves readily to smokeless operation unless constructed on the down draft principle, and using the better grades of bituminous coal.

In a residential furnace smokeless operation is difficult, as most of the carbon and other tarry volatile

products, contained in the volatile portion of the fuel, are carried off as smoke or are deposited as soot in the passages to the chimney. From the chimney the soot is emitted periodically in large flakes and deposited over the immediate neighborhood. These conditions, however, present one source of smoke in which the producer is the heaviest sufferer. This is due to the fact that most of the smoke and soot are usually deposited on the producers own property and because they are emitted at low levels and are not carried very far away. The amount of smoke from this source becomes negligible with the return of warmer weather, as natural gas is the universal fuel for domestic purposes, other than heating requirements. Coke and anthracite fuel can, however, be easily burned in most any sort of furnace for this purpose without the emission of smoke. In all residences, where bituminous coal of this District is used for heating purposes, much smoke and soot is the result.

Miscellaneous Services.

There are many minor sources of smoke in the city which help to swell the total amount of smoke, such as municipal and contractor's engines, tar and asphalt heaters, etc. These make smoke in the streets and discharge it at low levels, near doors and windows. Smoke from these sources is most annoying and is the cause of many complaints, for it probably causes more relative damage than other smoke emitted at higher altitudes. A strict enforcement of the city smoke ordinance would soon force the owner of such engines to burn a low volatile coal.

Part V.

Mechanical Engineering Survey of Stationary Plants.

The Object of the Survey.

The term "stationary plants" includes power and heating plants, mills, and factories. It refers to plants stationary in character as distinguished from the portable power plants in boats and locomotives, of which no particular survey has been made.

The object of the survey of stationary plants was to determine what are the typical conditions under which coal is burned in the Pittsburgh District; to describe and point out the merits of the different mechanical devices which are in use in the District; and to show how they work in actual practice, or, perhaps better, under the conditions under which they are installed.

Methods of Collecting Data.

In making the survey, one hundred and fifty-two typical stationary plants were visited for the securing of certain data and for observations as to smoke conditions. Examinations were made of these plants and the data secured, which is given in the tables of the Survey of Stationary Plants. In so far as the data or information was known, it was, in almost all instances, made available for the purposes of the Investigation, by the managers, engineers, or plant operators.

The plants visited were classified under five general headings:

1. Hand-fired plants.
2. Plants equipped with Chain Grate Stokers.
3. Plants equipped with Front-feed Stokers.
4. Plants equipped with Side Over-feed Stokers.
5. Plants equipped with Underfeed Stokers.

SMOKE OBSERVATIONS.

In order to make results of this Investigation comparable with the results of other Investigations, and to conform with the practice universally used throughout the country, and adopted by this city, the Ringleman system of estimating the relative blackness of the smoke issuing from stacks was adopted as a standard. This system has been adopted by the Federal Bureau of Mines and is clearly explained in the transactions of the American Society of Mechanical Engineers, Vol. XXI, December, 1899. The Ringleman scheme and the method of calculating the percentage of density of smoke will be found under Appendix III.

HAND-FIRED PLANTS.

Hand firing, which has been practiced from very early times, consists of charging the coal into the furnace at various intervals by hand and in amounts varying with the service to be rendered. The fuel bed is evenly covered with fuel and the coal is fired in small quantities at given intervals and according to one of three methods. In the spreading method each door of the furnace is fired at one firing and the fuel is spread evenly over the entire grate area. In the alternate method where there are two doors to each furnace only one door is fired at each firing in order to cover, at any one time, one-half of the grate surface with green fuel. The firings are made at equal intervals of time. The fuel is spread evenly over the portion of the grate fired. When a furnace has three doors, the usual plan is to put fresh coal on the front half of the grates fed by doors one and three, and on the rear half of the grate fed by door two. Then, at alternate intervals, supply fuel at the rear of numbers one and three grates, and on the front half of number two grate. This method of firing insures that one-half of the grate surface is at all times free from green coal. Furthermore, it has the advantage over the spreading method, where a horizontal flow of the gases is employed, in that one-half of

the fuel bed is in an incandescent state while the volatile products are being distilled from the freshly fired fuel, this aiding to complete combustion of these products. Means should be employed to promote a thorough mixing of the air and the volatile gases at all parts of the fuel bed and the combustion chamber. This mixing process cannot be easily accomplished, when the vertical style of baffling is employed, hence the alternate method of firing has no particular value with this style of baffling.

In the coking method, the fuel is charged on the dead plate immediately inside of the firing doors, remaining there until all the volatile products are distilled off, then it is pushed to the back portion of the furnace with a scraper and fresh fuel again charged on the dead plate when more coal is needed. The back of the furnace must be kept at a white heat at all times. With this method air should be admitted over the fire, especially at times of firing, and the grates should always be kept well covered. When used with the horizontal type of baffling this method has the advantage of compelling all gases, distilled from the fresh fuel charged at the front of the furnace, to pass over the bed of incandescent carbon, this tending to complete combustion before they are cooled below their ignition temperature. This method is inapplicable when the flow of gases is vertical instead of horizontal, and is not much used now as a very good fireman is required to get satisfactory results with it since the steam gauge and fire require more attention than the average fireman is liable to give them. Another serious objection is that the fire requires entirely too much stirring and raking. The spreading method of those described is most generally used and lends itself more readily to varying conditions, it being the only method usually considered when the vertical type of baffling is employed.

In order to obtain efficient operation and smoke elimination with a hand fired furnace, the utmost care must be exercised in firing, and in the use of the furnace auxiliaries. In connection with hand-fired furnaces there are quite a number of auxiliaries which, when properly in-

stalled and operated, tend to decrease the amount of s... made, and if a low volatile fuel is employed, smokel... operation can be obtained. These auxiliaries are usually classified according to the manner in which they are applied to the furnace. The first of these, so called furnace integrals, involve changes in the design and construction of the furnace and boiler setting and consist of such additions as Dutch ovens, fire tile, wing walls, piers, enlargement of combustion chamber and changes in method of baffling. The second consists of those devices which can be applied to any furnace without much change, such as steam jets with or without the admission of air over the fuel bed. The best results have been obtained when combinations of the first and second classes have been used.

With hand-fired furnaces, care in the manner of firing is of prime importance, and upon it too much emphasis cannot be placed in order to secure efficient and smokeless operation. There are factors associated with the hand-fired process due to which it does not adapt itself readily to smokeless operation and it is only by increased care in the manner of firing that the effect of these items can be minimized. In the hand-fired process, furnace doors must necessarily be opened to charge the fuel and attend fires, allowing simultaneously large amounts of cold air to be drawn into the furnace, thus decreasing the furnace temperature. Large amounts of gas are evolved at the time of firing the fresh fuel. On account of the decreased furnace temperature it is, at the same instant, most difficult to obtain complete combustion of the volatile gases. The common tendency among firemen is to fire as infrequently as possible, using a large amount of fuel at each firing, and without any regard to distributing it evenly over the entire grate. The hook and slice bar are liberally applied and very little care is usually exercised in their use. The length of time the doors are required to be kept open may be considerably decreased by firing fuel in smaller quantities, and using care to spread the fuel evenly over the grate at each firing. This eliminates the liberal use of the hook

and slice bar, keeps the fire in better condition and serves to eliminate smoke.

The tendency in hand-fired plants to use large sized coal entirely free from slack results in the production of large quantities of smoke. It requires less draft to burn this fuel than when some slack is mixed with it, although the fuel without any slack, gives a more intense fire. Sufficient attention is not given to the size of the fuel fired, and lumps of too large a size are used causing bad spots in the fire, necessitating liberal use of the hook and simultaneously causing smoke. There is also a common tendency among firemen to fill holes in the fire with fresh fuel instead of first raking incandescent fuel into these

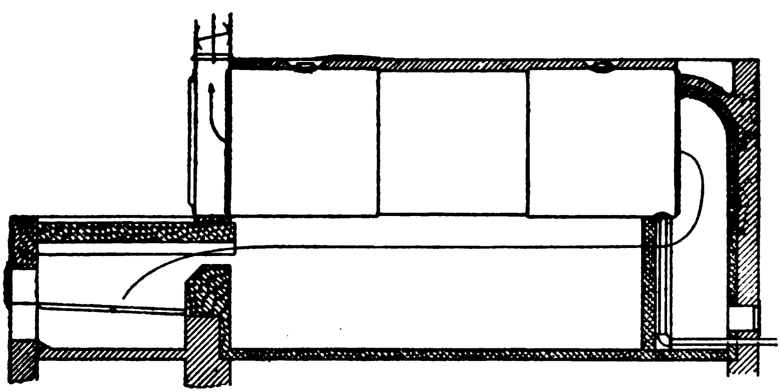

Figure 20—Dutch oven setting as applied to horizontal return tubular boiler.

holes and then charging the fresh fuel. Directions for proper methods of firing are given in Appendix III. Using a low volatile coal in a properly constructed furnace and following these directions, smokeless combustion and high efficiency will be obtained.

A Dutch oven as illustrated by Figure 20, when properly installed, provides one of the simplest methods of obtaining large coking area per square foot of grate surface. Such a furnace will produce very high temperatures when operated under the proper conditions. Although much better than the ordinary setting, the plain Dutch oven is too limited in length to prevent smoke formation except at very light loads, especially is this true

when applied to horizontal return tubular or vertically baffled water tube boiler, unless ample combustion space is provided. The combustion space is usually somewhat restricted and the velocity of the gases too high to permit of a thorough mixture before complete oxidation can take place. Steam jets, described later, placed across the front or along the sides of the furnace, and blowing steam and

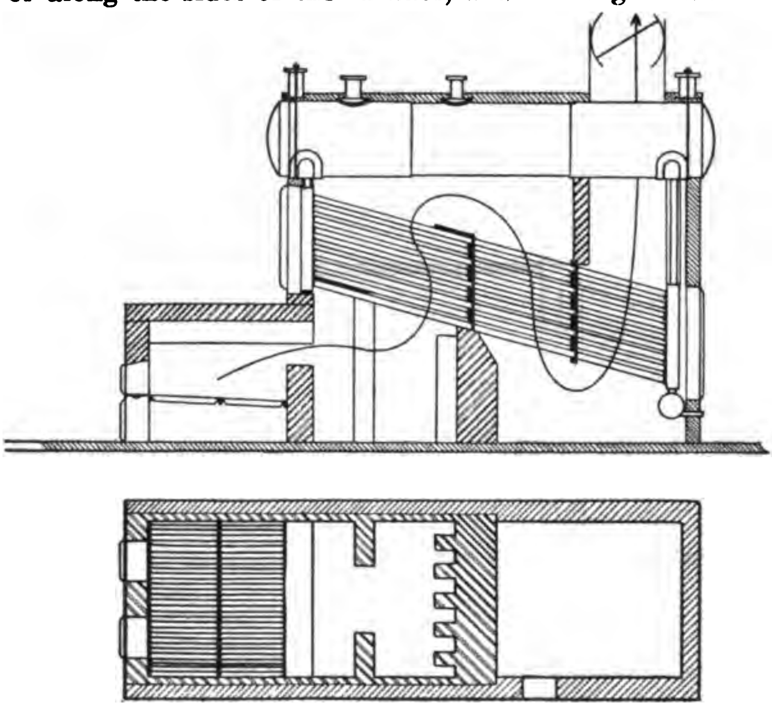

Figure 21—Kent's wing-wall furnace as applied to Babcock & Wilcox water-tube boiler.

air over the fire, are effective in mixing air and the combustible gases, also, an increase in the length of time the combustible gases are held in the furnace, will aid materially in decreasing the amount of smoke made.

The best results have been obtained by modifying the construction of the furnace so that the combustion space will be increased and extra baffles introduced to vary the direction and increases the length of travel of the gases before they become cooled. For best results these aux-

iliaries should be used in connection with the Dutch oven and steam jet, as previously explained.

The Dutch oven as applied to a B. & W. boiler supplemented with the installation of baffle piers known as Kent's wing-walls are shown by Figure 21. The purpose of these baffles being to increase the amount of refractory

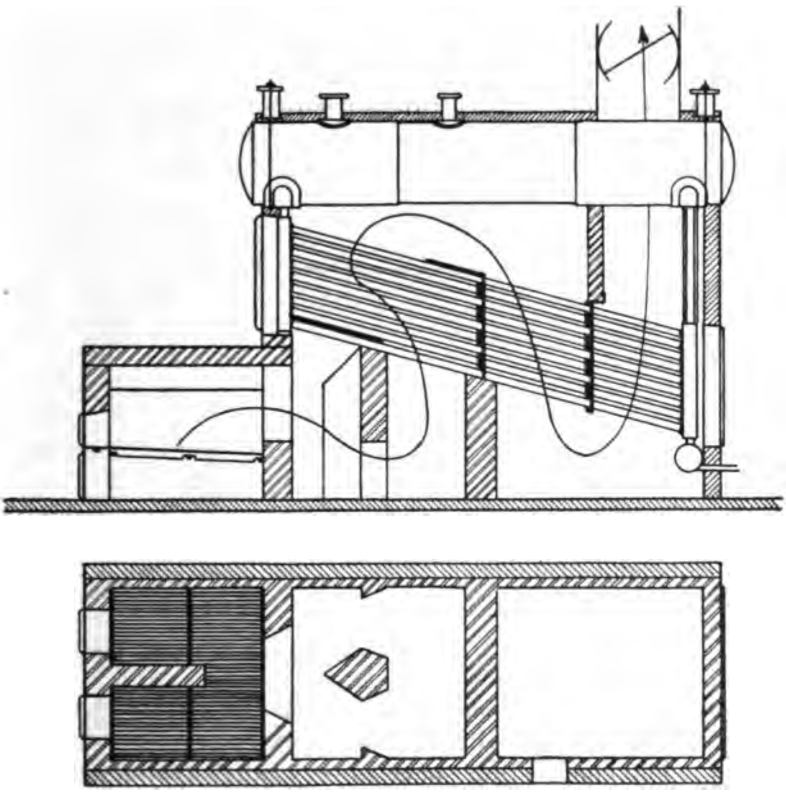

Figure 22—Wooley furnace applied to Babcock & Wilcox water tube boiler.

surface and length of travel of the hot gases. The piers and additional brick work acting as a regenerative furnace, absorbing heat when the fire is hottest and giving it up when fresh fuel is charged.

A modification of this furnace known as a Wooley smokeless furnace is shown as applied to a B. & W. boiler, Figure 22. The principal features of this furnace is the

provision of ample refractory surface and the manner of deflecting and mixing of the gases to obtain complete oxidation before they become cooled. The dividing wall shown in the center of the furnace and the restricted opening at the bridge wall lend themselves to the attainment of good results from the alternate method of firing. The heat from one side of the furnace being available to aid in the combustion of volatile products which are being distilled from the freshly fired fuel.

A horizontal return tubular boiler as usually installed is shown in Figure 23. This type of setting has little in its favor outside of the fact that it occupies the least

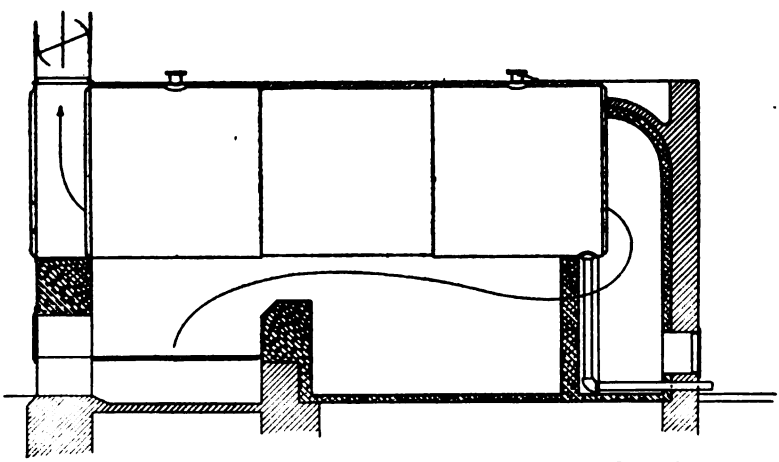

Figure 23—Usual method of setting horizontal return tubular boiler.

amount of space possible to develop the requisite power. It is cheap to install and has an extremely low up-keep cost. The combustion space is very much restricted. No provision is made to keep the gases at the proper temperature until combustion is completed, all the principles of proper combustion being neglected in the construction of this setting. This type of setting typifies one of the most persistent smokers in use.

Figure 24 illustrates an attempt to make some provision to maintain a high furnace temperature where the space available is very much restricted. This setting is much to be preferred over the one where the shell is ex-

posed directly to the fire as in Figure 23. When using the proper care, and a low volatile fuel, the amount of smoke made can be greatly decreased. The length of travel of the gases before they strike the cold surfaces of

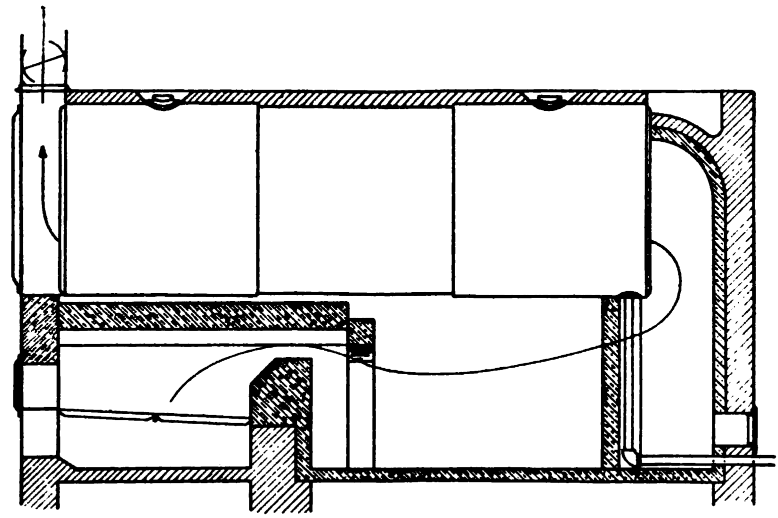

Figure 24—Horizontal return tubular boiler with fire-brick arch over grates and under boiler shell.

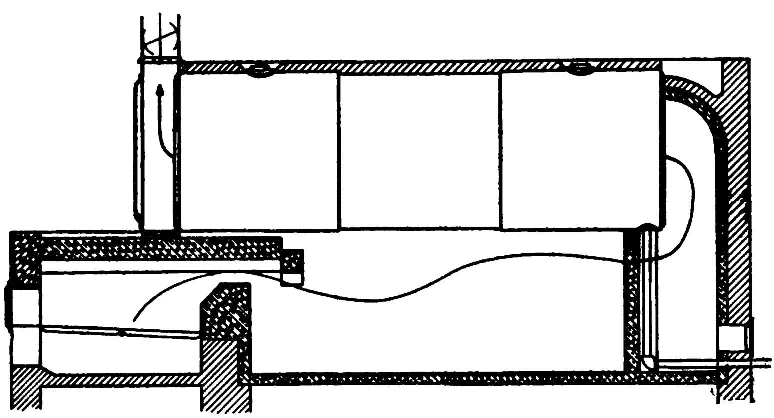

Figure 25—Horizontal return tubular boiler with fire-brick arch over grates.

the boiler is much too short, and unless steam jets are applied the gases do not remain in the furnace long enough and are not well enough mixed to be completely consumed before they are cooled below their ignition temperature.

Figure 25 illustrates another type of setting wherein the Dutch oven effect is still obtained and more of the heating surface is exposed to the action of the hot gases, thus making possible the development of higher ratings.

Figure 26 illustrates a Hawley down draft furnace applied to a Heine water tube boiler. This furnace has two sets of grate bars, the upper bars being formed of tubes through which the water of the boiler circulates. The lower bars are the ordinary type of bars used in any hand-fired furnace. In operation the coal is fired

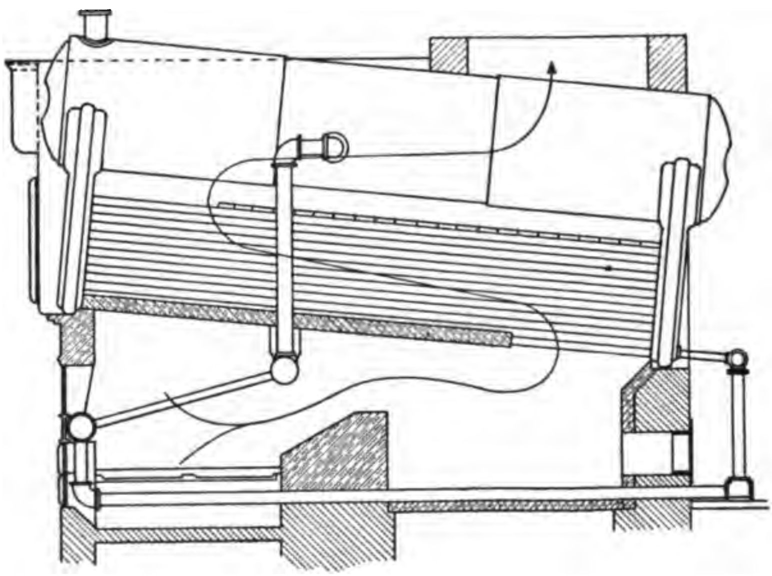

Figure 26—Heine water-tube boiler equipped with Hawley down-draft furnace.

on the upper grates and after being partially burned falls to the lower grate where it is completely consumed. The air for combustion passes down through the upper grates and up through the lower grates. The air and distilled gases from the fresh fuel are heated and intimately mixed in passing through the fuel bed and over the incandescent carbon on the lower grate, thus aiding complete combustion. Considerable care must be exercised to keep the upper grates well covered and prevent green coal getting through to the lower grates.

THE STEAM JET; ITS USE WITH HAND-FIRED FURNACES.

Steam jets are the devices in most common use in connection with hand-fired furnaces in order to obtain elimination of smoke. They may be classified according to the manner in which they are used.

1. Non-automatic steam jets:
   (a) Steam is used as a means of aspirating air into the furnace over the fire.
   (b) Steam alone is blown into the furnace over the fire.
2. Automatic steam jets:
   (a) Steam is used as a means of aspirating air into the furnace over the fire.
   (b) Steam alone is blown into the furnace over the fire.

As applied to furnaces, steam jets are usually non-automatic and the degree of efficiency with which they operate is entirely dependent upon the fireman, the consequence being that they are usually allowed to run longer than is required, or they are not used at all. Any steam jet that will properly mix the air and gases at the time of firing and also increase the length of time the gases are kept in the furnace will aid in the abatement of smoke. However, if the steam jets are allowed to operate longer than required they become a source of great waste of steam and will decrease the furnace efficiency, especially when air is aspirated into the furnace with the steam.

The best results have been obtained when the air is aspirated with the steam into a furnace having a refractory roof. When applied to an improperly designed furnace, or to one without ample refractory surface, the only purpose the steam jet accomplishes is to lengthen the time the gases are in the furnace and cause an intimate mixture of the air and gases. The steam jet is a very inexpensive device to install, but all factors being considered, it is usually a very expensive one to use. The idea that the steam jet increases the thermal value of the fuel is

erroneous. As much heat is required to dissociate a pound of steam into its elements, hydrogen and oxygen, as is given off when they recombine to form steam. Moreover, the fact must not be overlooked that it is extremely difficult to burn hydrogen in an ordinary furnace, so if some steam were dissociated, it is probable that some of the hydrogen would escape to the stack unburned. With hand-fired furnaces the automatic steam jet, which operates every time the door is opened for firing, slicing, or raking, and which is cut out of commission at times of cleaning is much to be preferred over the non-automatic jet in stationary practice.

TABLE 4—*Detail of data taken on hand-fired plants.*

No. of Instal-lation	Coal: Commercial Name	Coal: Size	Coal: Quantity per yr. Tons	Stoker: Kind of Stoker	Stoker: Thickness of Fire Inches	Stoker: Frequency of Cleaning	Furnace: No.	Furnace: Grate Area Sq. Ft.	Dimensions Feet and inches. Grate to H. S. Aver.	Grate to H. S. Min.	Width	Length	Front Furnace to Front Boiler	Height Coking arch Front	Height Coking arch Back	Length Coking Arch	Height Arch Rear Furnace
1	Pittsburgh	Run of Mine	....	Hand fired	14-15	2in 24 hrs.	3	48.0	....	......	8'-0"	6'-0"	0	None	....	....	....
2	do	Slack		do	12	2 " 24 "	4	35.0	....	......	7'-0"	5'-0"	0	do	....	....	....
3	do	do	....	do	12	2 " 24 "	6	22.5	2'-3"	......	4'-6"	5'-0"	0	do	....	....	....
4	do	do	33,300	do	18-20	....	4	70.0	3'-2"	2'-6"	10'-0"	7'-0"	0	do	....	....	....
5	do	do	....	do	12-18	....	2	53.7	1'-8"	......	10'-9"	5'-0"	0	do	....	....	....
6	do	do	....	do	12-18	....	4	53.7	1'-8"	......	10'-9"	5'-0"	0	do	....	....	....
7	do	2" Nut	....	do	18-24	4 " 24 "	6	64.4	6'-0"	4'-0"	10'-2	6'-4"	....	6'-0	6'-5"	8'-9"	....
8	do	Slack	12,400	do	12-16	2 " 24 "	11	25.0	2'-0"	......	5'-0"	5'-0"	0	None	....	....	....
9	do	Lump	270	do	4-8	Variable	2	25.0	3'-0"	2'-6"	5'-0"	5'-0"	0	do	....	....	....
10	do	Run of Mine	3,000	do	8-12	4 in 24 hrs	2	35.0	....	2'-6"	7'-0"	5'-0"	0	do	....	....	....
11	do	do	....	do	4-8	2 " 24 "	2	27.5	2'-4"	......	5'-6"	5'-0"	0	do	....	....	....
								35.0			7'-0"	5'-0"					
12	do	do	100	do	8-16	1 " 24 "	2	27.0	2'-6"	......	6'-0"	4'-6"	0	do	....	....	....
13	do	do	6,700	do	10-20	3 " 24 "	4	36.0	2'-6" to 2'-9"	2'-6"	6'-0"	6'-0"	1'-6"	do	....	....	....
14	do	Nut & Slack	900	do	3-5	2 " 12 "	1	42.5	....	......	5'-0"	8'-6"	0	do	....	....	....
15	do	Screened over ¾ bar	1,500	do	9	2 " 10 "	2	42.0	2'-2"	......	7'-0"	6'-0"	0	do	....	....	....
16	do	Nut	1,200	do	6	2 " 24 "	1	28.5	5'-6"	......	6'-0"	4'-9"	....	4'-0"	4'-0"	4'-0"	....
17	do	do	800	do	6	2 " 24 "	1	22.75	5'-6"	......	6'-8"	4'-11"	....	3'-0"	3'-0"	4'-0"	....
18	Wood	Shavings	....	do	4-12	....	1	....	....	......	5'-0"	....	0	None	....	....	....
19	Pittsburgh	Screened over ¾ bar	....	do	4-12	1 " 24 "	1	....	2'-6"			....	0	do	....	....	....
20	do	Run of Mine	....	do	12-18	2 " 12 "	1	14.6	....	1'-4"	4'-6"	3'-3"	0	do	....	....	....
21	do	Slack	900	do	10	2 " 24 "	2	30.25	2'-6"	......	5'-6"	5'-6"	0	do	....	....	....
22	do	do	650	do	8	2 " 24 "	1	27.5	2'-0"	1'-8"	5'-0"	5'-6"	0	do	1'-0"	....	....
23	do	Run of Mine	884	do	8-12	2 " 24 "	2	27.5	2'-6"	2'-0"	5'-6"	5'-0"	0	do	1'-6"	....	....
24	do	do	260	do	....	....	1	25.0	3'-0"	2'-2"	5'-0"	5'-0"	0	do	1'-6"	....	....
25	do	do	900	do	4-6	1 " 10 "	2	37.5	3'-6"	3'-0"	7'-6"	5'-0"	0	do	....	....	....

26	do	Slack		do	10	1" 11"	2	27.0			4'-6"	6'-0"	0	do			
27	do	do	3,750	do	10-12	2" 24"	3	24.0	1'-6"	None	4'-0"	6'-0"	0	do			
28	do	do	2,500	do	12" Front 5" Back	1" 24"	2						0	do			
29	do	Run of Mine	1,165	do	6	2" 24"	2	68.0	9'-0"	8'-0"	9'-0"	3'-9"	0	do			
30	do	Nut & Slack	3,326	do	12 Front 6-8 Back	3" 24"	3	42.0	4'-6"	3'-6"	7'-0"	6'-0"	0	do			
								30.0	2'-6" Back		5'-0"	6'-0"					
31	do	do	1,550	do	8	2" 16"	3	42.0	4'-0" front		6'-0"	7'-0"	0	do			
32	do	Run of Mine	9,200	do	20	2" 24"	5	49.5	6'-0"		4'-6"	11'-0"	0	do			
33	do	Lump	830	do	8	1" 12"	1	21.8	1'-6"		4'-8"	4'-8"	0	do			
34	do	Run of Mine	900	do	6-12	1" 24"	1	15.75	3'-0"	2'-2"	3'-6"	4'-6"	0	do			
								2-44			7'-4"	6'-0"					
35	do	do		do	6-12	2" 24"	3	1-49	1'-0"		8'-2"	6'-0"	0	do			
36	do	Slack	1,480	do	12	2-5" 24"	2	37.3			4'-8"	8'-0"	0	do			
37	do	Nut & Slack	1,750	do	10-12 on dead plate	3" 24"	2	32.0	2'-6"		8'-0"	4'-0"		1'-6"			
38	do	do		do	12	1" 24"	1	26.0	2'-6"		5'-0"	5'-0"	0	None	Arch over back of grates		
								2-21.4	2'-6"	2'-2"	4'-9"	4'-6"					
39	do	¾ Nut & Slack	3,700	do	6-8	4" 24"	4	2-33.0	2'-8"	2'-4"	6'-0"	5'-6"	0	do			
40	do	Nut	237	do			1	16.0	2'-0"	1'-6"	4'-0"	4'-0"	0	do			
41	do	Run of Mine	900	do	12-15	2" 24"	2	22.5		2'-0"	5'-0"	4'-6"	0	do			
42	do	Slack	275	do	8-12	1" 10"	1	18.0		2'-4"	4'-6"	4'-0"	0	do			
43	do	do	230	do	12	1" 10"	1	20.0	1'-10"	1'-6"	4'-0"	5'-0"	0	do			
44	do	Run of Mine	9,600	do	10"-14" F. 4"-8" Bk.	2" 24"	3	58.5	9'-0"	3'-0"	9'-0"	6'-6"	0	do			
45	do	Slack	950	do	8-10	1" 12"	3	40.0			5'-0"	8'-0"		4'-0"	4'-0"	5'-0"	
46	do	Run of Mine	1,850	do	8-10	2" 24"	2	25.0	3'-0"	2'-4"	5'-0"	5'-0"	0	None			
47	do	do	460	do	8	1" 10"	1	25.0	2'-9"	2'-0"	5'-0"	5'-0"	0	do			
									2'-6"								
48	do	do	3,900	do	6-8	2" 24"	2	36.0	3'-0"	2'-6"	6'-0"	6'-0"	0	do			
49	do	do		do	10-14		2										
50	do	Crushed Run of Mine	26,651	do	8-10	4" 24"	10	45.0			7'-6"	6'-0"	9'-0"	4'-0"	7'-0"	6'-0"	7'-0"
								20.0			5'-0"	4'-0"					
51	do	Run of Mine	4,385	do	6-15	4" 24"	3	30.0	2'-0"		6'-0"	5'-0"	0				
								26.5	2'-2"	2'-2"	4'-10"	5'-6"					
52	do	do		do	10-14		7	48.7	3'-0"	3'-3"	5'-6"	7'-6"	0				
53	Low Volatile	Slack	2,600	do	12		1	38.2			4'-8"	8'-0"	0				
54	Pittsburgh	do	1,265	do	8-14		2	22.0	16'-0"	14'-0"	4'-0"	5'-6"		1'-4"	1'-4"	2'-6"	
55	do	Run of Mine	1,000	do			2	22.5			5'-0"	4'-6"	0				
56	do	do	1,000	do			1	25.5			5'-8"	4'-6"	0				

TABLE 4—*Detail of data taken on hand-fired plants*—Continued.

No. of Instal-lation	Boilers						Load		
	Type	Builders Rated H. P.	No. Instal-led.	No. used to carry		Steam Pressure Lbs. per sq. in.	Requirement	Nature	Character
				Aver. Heavy Load	Aver. Light Load				
1	Heine Water Tube	650	3	3		100	Power	Uniform	Mfg.
2	Horizontal Return Tube	500	4	4		100	do	Variable	Mill
3	do	480	6			100	Power	do	do
4	B & W. Water Tube	1,500	4	4		105	do	do	do
5	2 Flue	180	4			115	do	do	do
6	2 Flue	360	8			115	do	do	do
7	Rust Water Tube	1,740	6	6		135	do	do	do
8	Horizontal Return Tube	860	11	11		125 on 2 95 on 9	do	Uniform	Factory
9	do	295	2	1		100-150	do	Variable	Mfg.
10	do	300	2	2		100-110	do	do	do
11	do	200	2	2		80	Power & heat	Fairly Uniform	Factory
12	do	185	2	1		80	do	Steady	do
13	do	600	4	4		100	Power	do	do
14	do	65	1			90-95	do	Fairly Steady	do
15	Erie City, Water Tube	400	2	2		90-100	Power & heat	Variable	do
16	Stirling, Water Tube	150	1	1		100	do	Uniform	do
17	Munroe, Water Tube	100	1	1		75-90	do	do	do
18	Horizontal Return Tube	45	1			30	Heat	do	do
19	do	100	1			100	Power	do	do
20	do	120	2	2		40-80	Heat & emergency	Variable	do
21	do	150	2	2		40	Power & Heat	do	do
22	do	60	1	1		75	do	do	do
23	do	105	2	1		90	do	do	do
24	do	80	1	1		80	do	do	do
25	do	240	2			100	Power	do	Shop
26	do	240	2	1		140	do	Uniform	Factory
27	do	300	3	2		90	Power & heat	do	Building
28	do	200	2	2		100	do	do	do

29	Heine Water Tube	300	2	1	1	90-100	Power, heat & light	Uniform	Power
30	B. & W. do	750	3	2	2	145	Power & heat	do	Building
31	Water Tube	525	3	2	1	115	Power	Variable	do
32	Locomotive	1,315	5	5	4	150	Power & heat	Fairly Uniform	do
33	Horizontal Return Tube	80	1	1	1	95	do	Variable	Factory
34	do	100	1	1	....	90	do	Variable	Building
35	2 Heine Water Tube 1 Keeler do	750	3	3	....	100	do	do	Shop
36	Locomotive	300	2	1	....	125	Power	Uniform	R. R. Yards
37	Water Tube	400	2	1	....	75	do	do	Power
38	Horizontal Return Tube	50	1	....	....	5-8	Heat	do	do
39	do	450	4	2	....	90-100	Power	do	do
40	do	20	1	1	....	60	do	do	Factory
41	do	110	2	1	....	90-100	do	do	Mfg.
42	do	45	1	1	....	90	do	Variable	Shop
43	2 Flue	25	1	....	....	65	do	do	Factory
44	Heine Water Tube	1,050	4	3	2	105-110	do	Uniform	do
45	Stirling do	240	3	2	2	125	Power & heat	do	do
46	Horizontal Return Tube	130	2	2	....	80	do	Variable	Packing
47	do	75	1	1	....	90	do	do	Factory
48	do	300	2	2	....	100	Power	Uniform	Factory
49	Heine Water Tube	550	2	2	....	105	do	Variable	Mill
50	Cahall do	2,500	10	9	....	120-125	do	Variable	Mill
51	Horizontal Return Tube	335	3	3	3	70	do	Variable	Mfg.
52	Internally Fired Water Tube	2,030	7	7	....	105	do	do	Mill
53	Locomotive	300	1	1	1	125	Power & heat	do	Round-house
54	Munroe Water Tube	104	2	2	1	60	do	do	Bldg.
55	Horizontal Return Tube	200	2	1	1	90	do	Uniform	do
56	Erie City Water Tube	100	1	1	1	90	do	do	do

TABLE 4—*Detail of data taken on hand-fired plants*—Continued.

No. of Installation	Rating				Draft						Breeching			
	Average Load.				Kind	Inches of Water.				Conditions Under Which taken	Distance Stack to nearest boiler Feet.	Size Feet	Where measured.	No. of Ells.
	Heavy		Light			Furnace	Rear of Boiler	Breeching	Base of Stack					
	Hrs. per day	Coal per day (tons)	Hrs. per day	Coal per day (tons)										
1	24	56.0			Natural	0.15				Normal				
						0.14								
2	24				do	0.20				do				
						0.11								
3	24				do	0.13				do				
4	24				do	0.32				do	6'-0"	4'x5'	At Setting	
5	24				do	0.33				do				
						0.23								
6	24				do	0.26				do				
						0.40								
7	24				do	0.42				do				
8	24				Forced					do				
9	4-5	0.9	4-5		Natural					do	8'-0"	5'x0.75'	At boiler	2
						0.23							Near	
10	24	10			do	0.29				do	12'-0"	3'x4'	Stack	1
11	12				do	0.44				do	0			0
12	10	3-4	14		do	0.12				do	12'-0"	2'x3'	Near boiler	1
						0.20								
13	24	25.0	24		do	0.24			0.60	do	10'-0"	6' (Dia.)	At Stack	0
14	13.5	3.0			do	0.17			0.42	do				
						0.12	0.14							
15	10	8.0			do	0.14	0.20			do	20'-0"	3'-2"x2'-6"	At boiler	1
16	12				do	0.25				do	0			0
17	12				do	0.15				do	18'-0"	2'-0"x2'-6"		2
18					do					do	9'-0"	2'-6"x2'-0"		1
19	10				do	0.30				do	0	Stack on	boiler	0
20	10-24	3.0			Induced					do		1'-6" dia.	Near Stack	4
						0.22								
21	10	3.0			Natural	0.27				do	10'-0"	3'-0" dia.	At Stack	0
22	24	2.25			do	0.12				do	0	Stack on	boiler	
23	24				do	0.14			0.22	do	0	do	do	

24					do	0.15			0.25	do	0	do	do	0
25	11				do	0.12				do	0	do	do	0
26	11				do	0.21				do	18'-0"	8'-0" dia.	At boiler	2
27	24				do					do	20'-0"	2'-8"		0
28	9		15		do	0.25		0.30		do	12'-0"			1
29	12				do	0.28	0.37		0.70	do	20'-0"	4'-0"x6'-0"	Near Stack	2
30	9		15		do	0.40		1.50		do	45'-0"	4'-0"x6'-0"	Near boiler	1
31	5				do	0.20		0.45		do	52'-0"	2'-6"x1'-6"		3
32	24	40	24	13-14	do	0.40			1.00	do	20'-0"	Stack on	boiler	2
33	12	2-2.5			do	0.18	0.28		0.47	do	0	2'-0" dia,		0
34	11	1.75	13	1-1.25	do	0.24				do	30'-0"	5'-0"x4'-9"	Nearest boiler	1
						0.24								
35	24				do	0.32				do	20'-0"			
36	24	3.95			do	0.18		0.35		do	12'-0"			1
37	24	4.85			do	0.23				do	8'-0"	3'-0"	At Setting	1
38	10	0.2-0.6	14		do	0.05				do	15'-0"	3'-0"	Near Stack	2
						0.22								
39	24				do	0.30				do	0'-8"	3'-0"		1
40	10				do					do	7'-0"	1'-0"x2'-0"	Middle	2
41	24				do	0.10				do	0	Stack on	boiler	0
42	9.5	0.85			do	0.10				do	0	do	do	0
43	10	0.75			do	0.10				do	0	do	do	0
						0.14								
44		31		18	do	0.18		0.55		do	18'-0"	6'-0"	At Stack	1
						0.20								
45	12	3.0-3.3			do	0.25				do				0
						0.13								
46	24				do	0.20				do		Stack on	boiler	
47	10	1.5			do	0.25				do	9'-0"	1'-10"x2'-0"		2
48	24	11.0			do	0.20			0.40	do		Stacks on	boilers	
49	24				do	0.20	0.45		0.75	do		do	do	
						0.20								
50	24	73.3			do	0.45			0.70	do		do	do	
						0.10								
51	24	14.6			do	0.20				do		do	do	
						0.12	0.20	0.38						
52	24				do	0.36	0.40	0.78		do		do	do	
53	24	2.5			do					do				
54	12	6.0	12	2.4	do	0.22				do				
						0.10								
55	10		14		do	0.15				do				
56	10		14		do					do				

TABLE 4—*Detail of data taken on hand-fired plants*—Continued.

No. of Instal-lation	Dampers: Kind	Dampers: Usual position	Stack: No.	Stack: Height Feet	Stack: Size Feet	Stack: Area Square Feet	Smoke Records: Total mins. of obser-vation	Smoke Records: Mins. in one hr. of 100 to 80 %	Smoke Records: Mins. in one hr. of 80 to 60 %	Smoke Records: Mins. in one hr. of Stack Clean	Smoke Records: Aver. per cent of Black Smoke	Smoke Records: Load during obser-vations.
1	None......	....	....		....	....	....	....	....	....	....	....
				1-60'-0"				13.75	2.50	28.75	30.5	
2	do	....	3	2-50'-0"	3'-0"	7.1	60	12.25	4.00	25.50	30.6	Normal
								4.75	2.25	48.75	11.0	
3	....	....	6	40'-0"	2'-6"	4.9	60	16.75	5.00	22.75	38.0	do
4	Automatic.		4	....	....	....	60	16.25	5.25	11.50	40.5	do
5	Hand......	Wide open........	2	70'-0"	3'-6"	9.6	60	9.50	2.75	25.75	25.0	do
								10.75	2.00	40.50	22.0	
6	do	do	4	70'-0"	3'-6"	9.6	60	11.25	2.00	41.00	22.0	do
								5.25	3.75	33.75	19.0	
7	Automatic.	....	6	80'-0"	....	....	60	0.25	.75	40.25	4.8	do
								15.25	1.25	34.00	31.0	
8	None......	....	11	65'-0"	2'-8"	5.9	60	3.25	.50	45.25	9.0	do
9	....	....	1	40'-0"	2'-8"	5.9	60	16.00	6.50	17.00	37.0	do
10	Hand......	¾ open........	1	90'-0"	5'-0"	19.6	60	23.25	4.50	12.25	45.0	do
11	None......	....	2	70'-0"	2'-0"	3.1	60	25.25	4.00	17.50	50.0	do
12	Hand......	Wide open........	1	70'-0"	5'-0"	19.6	60	4.50	1.75	32.00	16.0	do
13	do	do	1	145'-0"	6'-0"	28.3	60	28.75	10.50	0.00	65.0	do
14	None......	....	1	....	2'-6"	4.9	60	4.25	3.75	15.00	24.0	do
15	Hand......	do	1	108'-0"	4'-6"	15.9	60	25.25	10.00	2.50	59.0	do
16	do	do	1	72'-0"	3'-0"	7.1	60	0.00	1.50	29.00	11.0	Light
17	None......	....	1	50'-0"	4'-0"x4'-0"	16.0	60	0.75	2.25	21.00	15.0	Normal
18	....	....	1	70'-0"	3'-0"x3'-0"	9.0	60	0.00	0.00	52.75	0.3	do
19	Hand......	....	1	50'-0"	3'-6"	9.6	60	4.25	1.75	49.25	9.0	do
20	do	Wide open........	1	20'-0"	2'-0"	3.1	60	34.00	6.75	5.75	66.0	do
21	do	¼ to wide open....	1	100'-0"	3'-0"x3'-0"	9.0	60	9.75	2.50	29.00	24.0	do
22	do	¾ open........	1	40'-0"	2'-6"	4.9	60	6.50	0.75	47.75	13.0	do
23	do	Wide open........	2	60'-0"	2'-4"	4.3	60	13.75	3.25	32.50	29.0	do
24	do	do	1	60'-0"	2'-6"	4.9	60	5.50	4.50	30.00	20.0	do
25	do	do	2	....	2'-6"	4.9	60	2.50	2.25	27.75	12.0	do
26	do	do	1	60'-0"	3'-0"x3'-0"	9.0	60	9.50	2.50	34.75	22.0	do
27	do	do	1	130'-0"	3'-6"	9.6	60	2.50	6.50	4.00	18.5	do
28	do	do	1	135'-0"	2'-6"	4.9	60	2.25	2.00	48.25	10.0	do

29	do	½ open	1	110'-0"	6'-0"	28.8	60	5.50	2.50	39.75	14.2	do
30	do	do	1	300'-0"	3'-0"x4'-6"	13.5	60	7.50	5.00	35.25	21.3	do
								4.50	3.00	42.00	12.5	Readings at
31	do	Wide open	1	130'-0"	5'-0"	19.6	60	0.75	25.50	0.00	45.3	different times
32	do	½-¾ open	1	125'-0"	6'-6"	33.2	60	4.75	9.75	27.50	25.7	Normal
33	do	Wide open	1	75'-0"	2'-0"	3.1	60	3.75	3.50	38.00	15.1	do
34	do	do	1	175'-0"	2'-0"x2'-0"	4.0	60	2.50	2.00	31.00	11.5	do
35	do	do	1	140'-0"	6'-0"	28.8	60	8.25	5.25	28.00	25.0	do
36	do	do	1	90'-0"	3'-6"	9.6	60	4.25	2.00	17.75	16.0	do
37	do	¾ open	1	50'-0"	4'-6"	12.5	60	3.25	3.75	0.00	29.0	do
38	do	¼-½ open	1	75'-0"	2'-0"x2'-0"	4.0	60	0.00	1.50	50.75	4.0	do
		Wide open on 2	2	60'-0"	3'-0"	7.1						
39	do	None on 2	1	85'-0"	3'-6"	9.6	60	21.75	1.25	34.00	37.0	do
40	do	Wide open	1	30'-0"	2'-0"	3.1	60	2.25	1.00	26.00	16.0	do
41	None		2	55'-0"	2'-0"	3.1	60	18.00	3.00	24.75	37.0	do
42	Hand	Wide open	1	35'-0"	1'-8"	2.2	60	0.00	0.25	11.65	11.8	do
43	None		1	40'-0"	2'-0"	3.1	60	0.75	3.00	40.00	11.0	do
		¾ to Wide open										
44	Hand	Wide open	1	125'-0"	6'-3"	30.7	60	0.75	4.00	41.00	8.0	do
45	do	do	2	75'-0"			60	3.25	3.75	18.75	22.0	do
46	do		2	50'-0"	2'-6"	4.9	60	15.50	3.00	35.00	22.0	do
47	do		1	100'-0"			60	6.00	3.00	41.50	16.0	do
								12.75	5.00	35.00	28.0	
48	None		2	60'-0"	3'-6"	9.6	60	4.00	2.25	35.00	15.5	
49				100'-0"	2'-10"	6.3	60	0.50	1.00	49.75	5.0	Light
				4-100'-0"								
50	Automatic		10	6-115'-0"	3'-0"	7.1	60	1.25	3.25	29.50	16.0	Normal
					2-2'-0"	3.1		1.00	2.75	22.75	18.0	
51			3	50'-0"	1-4'-0"	12.6	60	3.00	4.75	21.75	13.0	Light
					3'-3"	8.3						
52	None		7	100'-0"	3'-6"	9.6	60	0.00	1.25	43.25	7.0	do
53			1	75'-0"	3'-0"	7.1	60	0.00	0.00			do
54			1	70'-0"	3'-0"	7.1	60	1.75	2.00	48.50	8.0	Normal
55	Hand	Wide open	1	200'-0"			60	0.25	1.50	52.50	4.0	do
56	do	do	1	200'-0"			60	4.50	2.50	43.00	12.0	do

TABLE 4—*Detail of data taken on hand-fired plants*—Continued.

No. of Installation.	Remarks.
1	....
2	Pier in combustion chamber. Type of installation, conditions and method of handling not conducive to smokeless operation.
3	Old installation, requires extreme care in handling to reduce amount of smoke.
4	Type of installation as constructed and operated not favorable to smokeless combustion.
5	Steam jets used, but equipment, manner of installation and operation not favorable to smokeless combustion.
6	Steam jets used but equipment, manner of installation and operation not favorable to smokeless combustion.
7	Type of setting, manner, of installation, operating conditions conducive to smokeless operation at low ratings.
8	Type of installation, general construction and operating conditions not conducive to smokeless operation.
9	General construction of installation and method of handling not conducive to smokeless operation.
10	Poorly installed with very small combustion chamber which is very unfavorable to smokeless operation.
11	General operating conditions, type and construction of equipment very unfavorable to smokeless operation.
12	Installation not of type favorable to smokeless operation but carefully operated and smoke kept down by this means.
13	Steam jets used, type of equipment manner of installation and method of handling not favorable to smokeless operation.
14	Type of installation and method of handling not favorable to smokeless operation.
15	Steam jets used but equipment does not lend itself to smokeless operation.
16	As installed and operated this equipment is not favorable to smokeless combustion.
17	Equipment and general conditions not favorable to smokeless operation.
18	Power requirements very light not much smoke produced in operation.
19	Steam jets supplied but not used. Type of equipment and method of operation not favorable to smokeless operation.
20	Old equipment, so installed and operated that it will produce smoke.
21	Steam jets used. Type of equipment, method of operation and type of setting not favorable to smokeless combustion.
22	Equipment and method of handling as well as surrounding conditions not favorable to smokeless operation. Operated at low rating.
23	Equipment fairly well installed and operating conditions good. Equipment not of type which lends itself readily to smokeless operation.
24	" " " "
25	Equipment poorly installed but well operated, general surrounding and operating conditions good.
26	Old equipment, very poorly installed, general conditions and method of operation fair.
27	Type of installation, method of construction and operation, also general conditions poor.
28	Wooley furnace, fairly well operated.
29	Good equipment, properly installed and operated, general surrounding and operating conditions good.
30	Good equipment, properly installed and operated, plant conditions good.
31	Steam jets but not in use, two boilers fired by gas, breeching long and tortuous. Operating conditions poor.
32	Fair equipment but not very well suited to conditions. Operating conditions and manner of operation good.
33	Steam jets used. Fair equipment poorly installed but well operated.
34	Steam jets used. Old equipment, poorly installed and operated. General surrounding and operating conditions poor.
35	Good equipment but poorly installed and operated.
36	Good equipment and well operated but not very well suited to conditions.
37	Fair equipment, fairly well installed and operated.

38	Equipment ample in size for requirements.
39	Old equipment but in good condition. Poorly set but well operated.
40	Old equipment, type of setting and manner of handling not conducive to smokeless operation.
41	Old equipment, poorly installed and operated, general operating conditions poor.
42	Steam jets used. Old equipment poorly installed and operated, not much care exercised in firing.
43	Old equipment, poorly installed and operated, not much care used in firing.
44	Equipment good, fairly well installed but not much care exercised in firing.
45	Equipmnt good, fairly well installed, general operating conditions good but not much care used in firing.
46	Steam jets used. Old equipment not properly installed or operated. General conditions poor.
47	Old equipment poorly installed and operated.
48	Good equipment but not properly installed. Well operated and general conditions good.
49	....
50	Good equipment, properly installed, general plant conditions very poor, firing poorly done.
51	Steam jets used. General conditions poor.
52	Old equipment in poor condition, not much care exercised in operation.
53	Boiler being operated considerably below rating.
54	....
55	Good equipment but not properly installed. General operating conditions and operation fair.
56	Good equipment, fairly well installed and operated.

Results of the Survey of Hand-fired Plants.

Examinations were made of fifty-six hand-fired plants. Of these, fifty-four used Pittsburgh coal, one wood, and one low volatile coal. These plants varied in size from twenty to twenty-five hundred boiler horse power, and contained from one to ten boilers per plant. Horizontal return tubular boilers were installed in thirty-two of these plants, and the old style, two flue boilers in three plants. In thirteen of these plants, water tube boilers were installed with a refractory roof over the grates, consisting either of fire tile or arches. The steam jet was installed in twelve out of the total number of plants surveyed, but was only in use in ten, and in no case was it supplied, where refractory surfaces were installed, over the grates. Some refractory surfaces were provided over the fire in ten plants, not including boilers with fire tile roofs. In six plants the refractory surface was ample in size to be classified as a coking arch, and varied in length from 2 ft. 6 in. to 8 ft. 9 in. Steady or uniform loads were carried by thirty plants. The depth of fire varied from 3 in. to 24 in. The draft in the furnace at forty-eight plants varied from 0.10 in. to 0.45 in. of water, and at the base of the stack in ten plants, from 0.22 in. to 1.00 in. water.

Observations were made upon fifty-one stacks connected to boilers without fire tile roofs over the furnace, or what may be classified as a coking arch over the fire, showing the following results:

The average of these observations shows 12.2 minutes per hour of smoke equal to or greater than 60 per cent. black; 29.8 minutes per hour when no smoke issued from the stack; and an average of 23.4 per cent. black smoke. Observations on these stacks show a maximum of 40.8 minutes per hour, and a minimum of 0.00 minutes per hour of smoke equal to or greater than 60 per cent. black, maximum of 52.8 minutes and a minimum of 0.00 minutes per hour clean stack, with a maximum of 66.0 per cent. and a minimum of 0.3 per cent. black smoke.

Observations of eleven stacks connected to boilers equipped with Dutch ovens, arches over the fire greater

than 2 ft. 6 in. in length, or furnaces of boilers having a fire tile roof, show the following results:

The average of the observations show 5.2 minutes per hour of smoke equal to or greater than 60 per cent. black; 34.5 minutes per hour when no smoke issued from the stack; and an average of 13.6 per cent. black smoke from observations. Observations on these stacks show a maximum of 13.5 minutes per hour, and a minimum of 1.00 minute per hour of smoke equal to or greater than 60 per cent. black; maximum of 48.5 minutes and a minimum of 18.8 minutes per hour clean stack; with a maximum of 25 per cent. and a minimum of 4.8 per cent. black smoke.

MECHANICAL STOKERS.

A majority of the larger plants surveyed, and quite a number of the smaller ones are equipped with mechanical stokers. The types of stokers now on the market vary in the manner of charging and handling the fuel, carrying it through the various stages of combustion, and in the method of getting rid of ash and clinker. They may be classified as follows:

1. Overfeed Stokers:
   - (a) Chain-grates.
   - (b) Front-feed.
   - (c) Side-feed .
2. Underfeed Stokers.

CHAIN-GRATE STOKERS.

The chain grate represents one of the oldest forms of mechanical stokers in operation, and is no doubt one of the most popular types in use throughout the middle West, and in districts where the poorer grades of bituminous coal are used. This type is very popular in districts where the coal used is of a free burning, non-coking nature. It embodies a moving endless chain of grate bars mounted on a frame with provision for uniform and continuous

feeding of the coal into the furnace, the fuel and grate moving together.

Fuel is fed into the furnace from a hopper placed at the front end of the furnace, the thickness of the fuel bed being regulated by means of a gate placed at the back end of the hopper. This gate may either be raised or lowered so as to supply the fuel in sufficient quantity to develop the required power. Back of this hopper and extending over the entire width of the furnace is an ignition arch which ignites the fuel as it leaves the hopper, the length of this arch varying greatly with different makes of stokers and class of fuel used. The present tendency is to increase materially the length of this arch and the distance between the tube surfaces of the boiler and the grate. The furnace side of the gate is also faced with refractory material which aids considerably in securing rapid ignition of the fuel as it is fed to the furnace. The speed of the chain grate is controlled by the speed of the driving engine or motor which operates the grate through a system of gears. The operations of feeding the coal, carrying it through the progressive stages of combustion, removing the ashes and maintaining a clean grate are practically automatic.

The coal from the hopper begins to ignite as it leaves the gate and passes under the ignition arch, the moving grate carrying the burning coal through the various stages of combustion from the front to the rear of the furnace. The grate passes under the bridge wall and over the sprockets at the rear of the furnace, the ashes and clinker being automatically dumped into a pit. The speed of the chain should be so regulated that the fuel fed is completely consumed as it reaches the bridge wall. Care should be exercised to keep the back portion of the grate covered with incandescent fuel.

Plants equipped with chain-grates are made to carry a variable load with good results by changing the speed of grate, the thickness of the fire and the position of the damper to suit the load. Care must be used, however, not to reduce the draft to such an extent that the stack will

smoke. In some plants where the variations in load are not so marked, changes can usually be met only by varying the speed of the grate and the position of the damper .

Both the speed of the grate and the slope of the ignition arch are very important factors. The grate may be run so fast that volatile matter is given off as far back

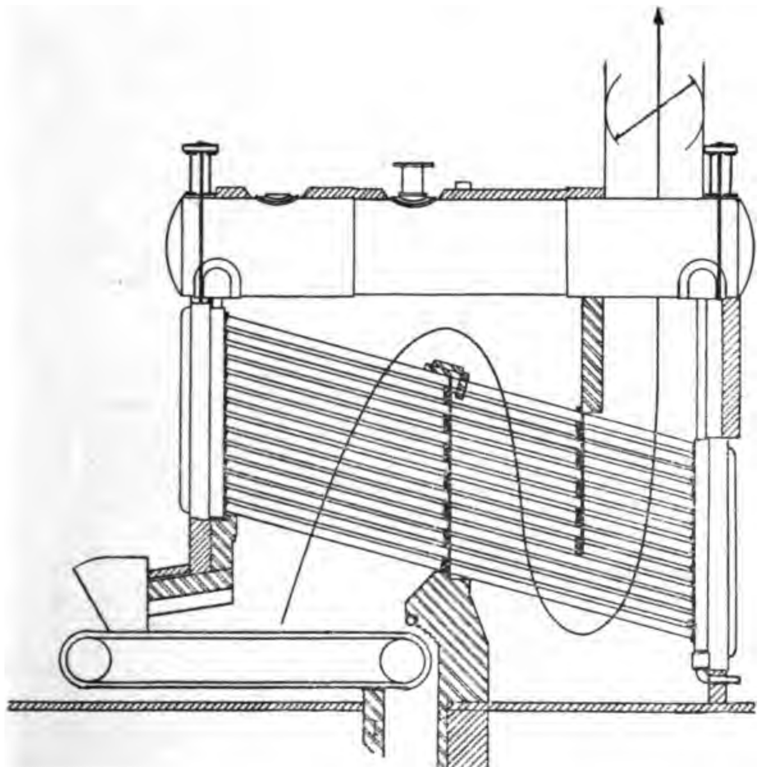

Figure 27—Chain-grate with short ignition arch as applied to Babcock & Wilcox water-tube boiler.

as the center of the grate. In this case there is not only loss from incomplete combustion of the gases, loss of unconsumed carbon in the ash, but the grate may be injured by warping, due to the presence of live coal in the ash pit. A chain-grate plant may run very inefficiently if fire is carried only on the front half of the grate, as sometimes happens. This, however, allows a wide latitude in

operation with the maintenance of a clean stack, especially when the boiler is properly set.

The almost universal type of setting of chain grate, as applied to the B. & W. boiler with the usual method of baffling, and as used in the Pittsburgh District is shown in Figure 27. In this type of setting the arch is far too short, thus not providing ample refractory service to maintain the gases at their kindling temperature until combustion is complete. The combustion space is re-

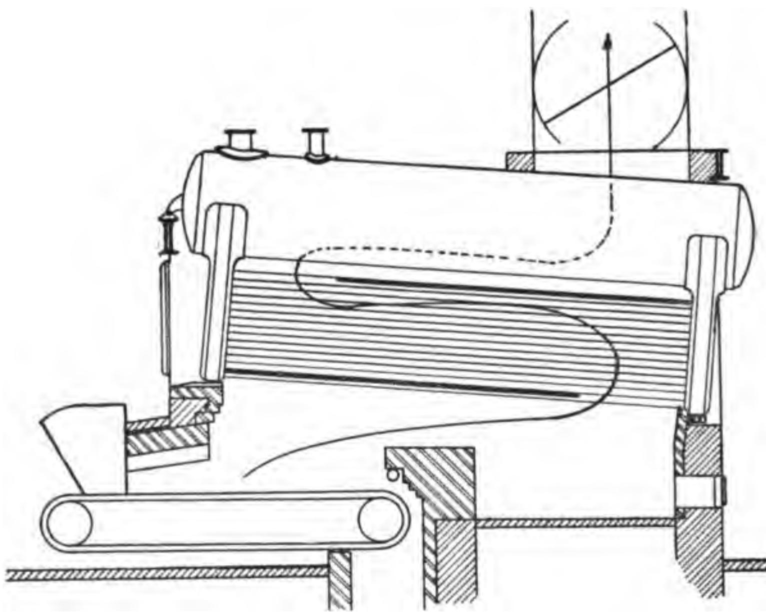

Figure 28—Chain-grate with sort ignition arch as applied to Heine water-tube boiler.

stricted, and the length of travel of the gases before they strike the cold surfaces of the boiler is much too short. This prevents thorough mixing of the air and gases, and results in incomplete combustion. This type of setting does not readily adapt itself to smokeless operation when boilers are operating at or above rating, and only by means of short fires and high air excess can smoke be eliminated.

A chain-grate with short arch, as applied to horizontal water tube boiler with horizontal type of baffle is

illustrated by Figure 28. By encasing the lower row of tubes of the boiler with fire tile, a refractory roof is provided, along which the gases travel, increasing the time allowed for combustion. In this type of setting, the space provided in the combustion chamber for the mixing of the

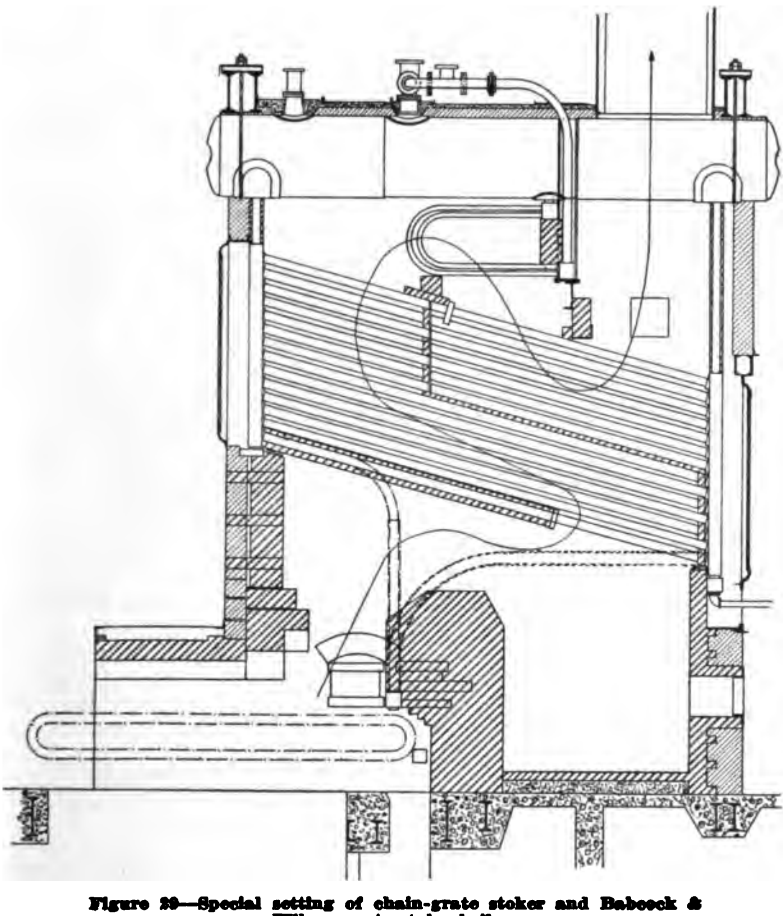

Figure 29—Special setting of chain-grate stoker and Babcock & Wilcox water-tube boiler.

air and gases is somewhat restricted when compared to best practice.

Figure 29 represents a chain-grate stoker as applied to a B. & W. boiler of a special type of setting, and in use at North West Station of the Commonwealth Edison Com-

pany, Chicago, Ill. This is known as the Sewall type of setting, and has all the commendable features that lend themselves to smokeless and efficient operation.

Figure 30 represents a chain-grate as applied to a B. & W. boiler in which the usual manner of baffling the

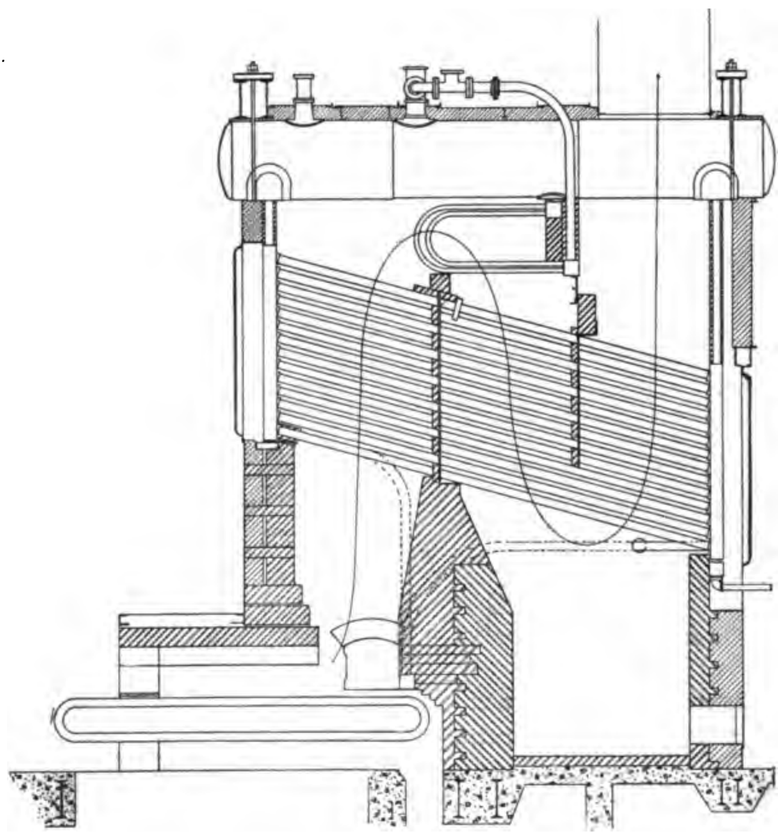

Figure 30—Special setting of chain-grate stoker and Babcock & Wilcox water-tube boiler.

gases has been retained. This type of setting is being used by the Commonwealth Edison Company of Chicago, Ill., in part of the equipment of their Quarry Street and North West Stations. In this setting the long coking arch has been retained, the ample combustion space in-

sures thorough mixture of the air and gases, and the length of travel of the gases is considerably increased over that usually used with the regular type of setting.

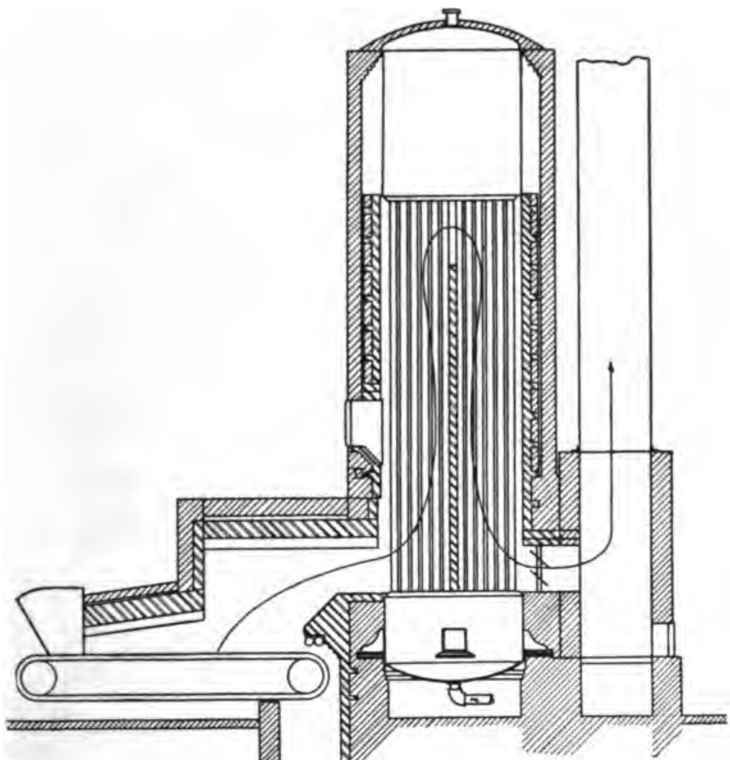

Figure 31—Chain-grate stoker as applied to Wickes vertical water-tube boiler.

Figure 31 shows a chain-grate as applied to a Wickes water tube boiler.

Figure 32 shows a chain-grate stoker as applied to a Stirling water tube boiler.

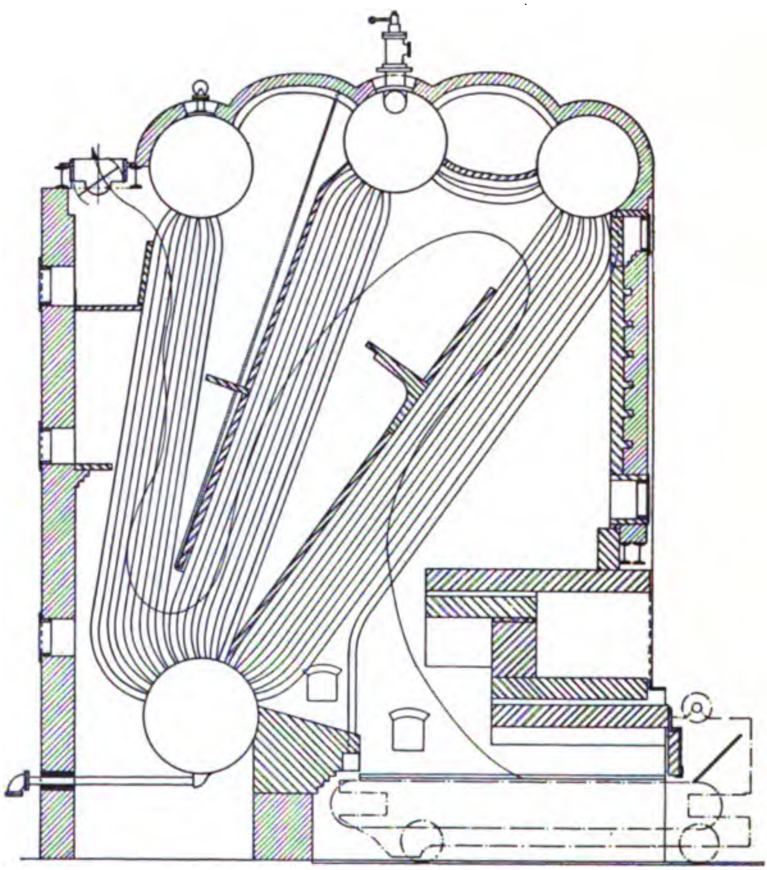

Figure 32—Chain-grate stoker as applied to Stirling water-tube boiler.

TABLE 5—*Detail of data taken on plants equipped with chain-grate stokers.*

No. of Instal-lation	Coal			Stoker			Furnace.										
									Dimensions Feet and inches.								
	Commercial Name	Size	Quantity per yr. Tons	Kind of Stoker	Thickness of Fire Inches	Frequency of Cleaning	No.	Grate Area Sq. Ft.	Grate to H. S. Aver.	Grate to H. S. Min.	Width	Length	Front Furnace to Front Boiler	Height Coking arch Front	Height Coking arch Back	Length Coking Arch	Height Arch Rear Furnace
1	Pittsburgh	Slack	....	Green chain grate	4-6	Continuous	8	60.7	10'-0"	5'-0"	6'-6"	9'-4"	11'-3"	11"	1'-6"	4'-0"	4'-6"
2	do	do	11,500	do	6-7	do	4	99.0	6'-0"	....	9'-0"	11'-0"	3'-0"	10"	1'-3"	5'-0"	5'-0"
3	do	Crushed Run of Mine	....	B & W do	6	do	2	55.5	7'-0"	....	7'-5"	7'-6"	1'-6"	12"	2'-6"	3'-0"	....
4	do	do	....	" do	6	do	6	50.8	6'-0"	4'-0"	6'-6"	7'-10"	8'-0"	12"	1'-0"	3'-0"	5'-0"
5	do	Slack	50,000	" do	6	do	20	52.0	8'-0"	6'-0"	6'-6"	8'-0"	10'-0"	16"	1'-4"	2'-6"	5'-0"
6	do	do	10,000	Chain grate	4-6	do	2	101.0	8'-0"	6'-0"	6'-0"	8'-5"	1'-6"	16"	1'-9"	3'-6"	4'-3"
7	do	do	6,500	Playford chain grate	7	do	2	64.0	10'-0"	6'-0"	8'-0"	8'-0"	9'-0"	10"	1'-7"	4'-0"	4'-0"
8	do	do	....	B & W do	7	do	4	57.3	7'-0"	3'-0"	7'-2"	8'-0"	8'-6"	16"	1'-8"	3'-0"	5'-0"
9	do	do	17,500	Green do	4-5	do	5	95.0	6'-0"	4'-6"	10'-0"	9'-5"	3'-0"	9"	2'-0"	3'-0"	....
10	do	do	4,000	Playford do	6-7	do	2	44.5	7'-0"	3'-0"	6'-8"	6'-8"	8'-0"	12"	1'-0"	8'-0"	....
11	do	do	4,250	Green do	4-5	do	2	49.0	6'-0"	4'-0"	7'-0"	7'-0"	0'-0"	12"	1'-2"	2'-6"	....
12	do	do	1,320	do do	4	do	1	52.2	6'-0"	5'-6"	5'-6"	9'-6"	3'-0"	12"	3'-0"	5'-0"	....
								49.0			5'-6"	9'-0"	4'-0"				
13	do	do	29,500	do do	6-8	do	10	66.0	....	....	6'-6"	10'-0"	4'-0"	9"	1'-3"	3'-0"	....
14	do	do	11,500	do do	4	do	8	75.0	....	....	7'-6"	10'-0"	3'-8"	12"	1'-5"	5'-0"	....
								63.0	4'-0"		7'-0"	9'-0"	4'-0"			4'-0"	
15	do	Nut & Slack	2,900	do do	4-6	do	3	72.0	11'-0"	4'-0"	8'-0"	9'-0"	3'-0"	15"	2'-0"	3'-0"	....
16	do	Slack	3,000	do do	4-6	do	2	56.0	7'-0"	4'-0"	7'-0"	8'-0"	3'-0"	11"	2'-3"	5'-0"	....
17	do	Nut & Slack	2,700	do do	6	do	2	50.0	....	....	5'-0"	10'-0"	3'-4"	12"	2'-0"	5'-0"	....
18	do	do	42,000	B & W do	4-6	do	12	52.0	4'-6"	3'-0"	6'-6"	8'-0"	1'-6"	12"-17"	12"-17"	4'-0"	....
19	do	do	7,225	Green do	6	do	3	75.0	5'-0"	....	7'-6"	10'-0"	3'-0"	18"	2'-0"	5'-0"	....
20	do	Slack	8,000	B & W do	6	do	3	....	....	....	....	....	....	....	....	....	....
21	do	do	4,000	do do	6	do	2	....	....	....	....	....	....	....	....	....	....
22	do	do	80,000	Playford do	6	do	8	121.0	....	....	11'-0"	11'-0"	0-0	1'-3"	2'-2"	4'-0"	....
23	do	¾ Nut & Slack	9,000	do do	4-6	do	2	81.0	5'-0"	3'-0"	9'-0"	9'-0"	11'-0"	1'-6"	1'-6"	4'-0"	5'-6"
24	do	Crushed Run of Mine	124,500	Mansfield do	7	do	26	56.0	....	....	7'-0"	8'-0"	7'-6"	1'-3"	1'-3"	4'-0"	5'-0"
25	do	do	26,650	do do	7	do	8	54.0	....	....	6'-6"	8'-4"	1'-0"	1'-3"	1'-9"	3'-9"	....

26	do	do	55,000	do	do	6	do	14	55.3	....	....	6'-6"	8'-6"	1'-0"	1'-6"	1'-6"	3'-0"	....
27	do	do	23,600	do	do	6	do	8	55.3	....	....	6'-6"	8'-6"	1'-0"	1'-6"	1'-6"	3'-0"	....
28	do	do	59,800	do	do	6	do	18	55.3	....	....	6'-6"	8'-6"	10'-0"	1'-3"	1'-3"	4'-0"	....
29	do	do	33,500	do	do	8	do	10	56.0	....	....	7'-0"	8'-0"	7'-6"	1'-3"	1'-3"	4'-0"	....
30	do	Slack	16,200	4 B & W 1 Playford	do do	4-5	do	5	30.0-50.0 60.0-80.0	....	....	....	....	....	....	....	9'-0"	....
31	do	do	4,200	Playford	do	6	do	2	64.7	....	....	8'-6"	7'-6"	1'-3"	1'-6"	2'-6"	4'-0"	....
32	do	Crushed Run of Mine	60,516	Mansfield	do	7	do	16	54.0 42.5	....	....	6'-6"	8'-4" 8'-0"	1'-0"	1'-3"	1'-9"	4'-0"	....
33	do	do	36,750	do	do	4-6	do	12	52.0	....	....	6'-6"	6'-6"	1'-0"	1'-6"	1'-6"	3'-0"	....

TABLE 5—*Detail of data taken on plants equipped with chain-grate stokers*—Continued.

No. of Instal-lation	Boilers						Load		
	Type	Builders Rated H. P.	No. Instal-led.	No. used to carry		Steam Pressure Lbs. per sq. in.	Requirement	Nature	Character
				Aver. Heavy Load	Aver. Light Load				
1	Water Tube	2,000	8	7	....	150	Power	Variable	Mill
2	B. & W. Water Tube	1,800	4	2-3	2	125	Power & refrigeration	Uniform	Factory
3	B. & W. do	600	2	2	....	100	Power	Variable	Mill
4	Cahall do	1,800	6	3	....	100	do	do	do
5	Cahall do	5,000	20	16	....	130	do	do	do
6	Stirling do	1,000	2	2	....	130	do	do	do
7	Rust do	600	2	2	....	115	do	do	do
8	Cahall do	1,000	4	4	....	115	do	do	do
9	B. & W. do	2,500	5	4	....	125	do	do	do
10	Cahall do	500	2	2	....	125	do	do	Mfg.
11	Stirling do	520	2	2	....	100	Power & refrigeration	Uniform	Factory
12	B. & W. do	250	1	1	....	125	Power & heat	do	Mfg.
13	B. & W. do	3,370	10	6	4	150	Power, heat & light	Variable	Bldg.
14	B. & W. do	2,400	8	4	2	150	Power & heat	do	do
15	B. & W. & Heine do	750	4	1	1	115	do	Uniform	do
16	B. & W. do	508	2	1	1	120	do	Variable	do
17	B. & W. & Aultman Taylor do	500	2	1	1	110	do	do	do
18	B. & W. do	3,600	12	10	7-8	165	Power	do	Power
19	B. & W. do	1,350	3	2	....	110	Power & heat	Variable	Bldg.
20	B. & W. do	1,050	3	3	....	110	Power	Uniform	Mfg.
21	Cahall do	500	2	1-2	....	110	do	do	do
22	Stirling do	4,800	8	8	....	100-150	do	Variable	Mill
23	Wickes do	400	2	2	....	100-120	do	Uniform	Mfg.
24	Cahall do	6,500	26	22	....	125-130	do	Variable	Mill
25	B. & W. do	2,000	8	7-8	....	120-125	do	do	do
26	B. & W. do	3,500	14	13-14	....	110-125	do	do	do
27	B. & W. do	2,000	8	7-8	....	110-125	do	do	do

28	Cahall	do	....	4,500	18	12	....	120-130	do	do	do
29	Cahall	do	....	2,500	10	9-10	....	120	do	Fairly uniform	do
30	B. & W.	do	....	1,250	5	5	....	110	do	Variable	Factory
31	B. & W.	do	....	800	2	1	....	110	Power & heat	do	Bldg.
32	B. & W.	do	....	4,000	16	14	....	120	Power	do	Mill
33	B. & W.	do	....	3,000	12	10	....	110-125	do	do	do

Table 5—*Detail of data taken on plants equipped with chain-grate stokers*—Continued.

No. of Installation	Rating: Average Load. Heavy: Hrs. per day	Rating: Average Load. Heavy: Coal per day (tons)	Rating: Average Load. Light: Hrs. per day	Rating: Average Load. Light: Coal per day (tons)	Draft: Kind	Draft: Inches of Water. Furnace	Draft: Inches of Water. Rear of Boiler	Draft: Inches of Water. Breeching	Draft: Inches of Water. Base of Stack	Draft: Conditions Under Which taken	Breeching: Distance Stack to nearest boiler Feet.	Breeching: Size Feet	Breeching: Where measured.	Breeching: No. of Ells.
1	12		12		Natural	0.15	0.20	0.80			6'-0"	5'-5"x2'-0"	Rear of boilers	0
						0.18								
2	24	40	24		Induced	0.28								0
3	24				Natural	0.23	0.35					Stack straddles boilers		
4	24				do							Stacks on boilers		0
									0.54					
5	24				do	0.35			0.58			do	do	0
						0.12								
6	24				do	0.13			0.55			do	do	0
7	24				do	0.33	0.44				16'-0"	3'-0"x5'-6"		1
8	24				do	0.31	0.37							0
					do	0.17	0.34							
9	24	55-60			do	0.25	0.53							0
10	10				do	0.25						Stacks on boilers		0
11	24	17			do	0.15	0.27							1
12	12				do	0.23	0.42					3'-6"x2'-6"	At Setting	2
13	10	107	14	56	do			0.75			12'-0"	7'-3"x11'-0"	At Stack	1
14	24				do						15'-0"			1
15	10		14		do	0.30					10'-0"	4'-6"	At Stack	
													Between	
16	12		12		do			0.70			46'-0"	3'-4"	boilers	5
17	8		16		do			0.70			25'-0"			2
18	12	150	12	96	do		0.30				4'-0"			1
					do	0.20								
19	12	22	12	18	do	0.22					20'-0"	5'-0"x5'-0"	At Stack	1
20	10				do	0.23		0.38	0.60		6'-0"	3'-0"x3'-7"	At boiler	1
21	10				do									
22	24				do	0.18			0.72		Stack on each boiler			0
23	24	30.0			do	0.15			0.90		do near boiler			0

24	24	341.0	....	....	do	0.40	....	....	0.55 0.75	....	....	Stacks on	boilers	0
25	24	73.3	....	....	do	0.30	....	....	0.70	....	0	3'-0"x3'-6"	At boiler	1
26	24	150.8	....	....	do	0.30	....	....	0.70	....	0	3'-0"x3'-6"		1
27	24	67.4	....	....	do	0.25	....	....	0.60	....	0	3'-0"x3'-6"	....	1
28	24	162.8	....	....	do	0.40	....	....	0.80	....	0	Stack on	boiler	0
29	24	90.0	....	....	do	0.35	....	....	0.95	....	....	do	do	0
30	24	54.0	....	....	do	....	....	....	....	....	....	Stacks at boiler		....
31	18	....	6	....	do	0.18	....	....	....	....	35'-0"	5'-0"x6'-6"	....	4-45° 2-90°
32	24	165.0	....	....	do	0.24 0.20	....	....	0.60 0.40	....	0	3'-0"x3'-6"	At boiler	1
33	24	100.0	....	....	do	0.30	....	....	0.65	....	10'-0"	3'-0"x3'-6"	do	2

TABLE 5—*Detail of data taken on plants equipped with chain-grate stokers*—Continued.

No. of Instal-lation	Dampers		Stack				Smoke Records					
	Kind	Usual position	No.	Height Feet	Size Feet	Area Square Feet	Total mins. of obser-vation	Mins. in one hr. of			Aver. per cent of Black Smoke	Load during obser-vations.
								100 to 80 %	80 to 60 %	Stack Clean		
1	Hand	¾ open	4	125'-0"	5'-0"	19.6	60	0.00	0.00	46.50	4.6	Normal
2	do	Wide open	1	80'-0"	6'-0"	28.3	60	0.00	0.00	60.00	0.0	do
3	None		1	116'-0"	5'-6"	23.8	60	0.00	0.00	41.75	6.1	do
4	do		6				60	0.00	0.00	24.75	15.0	do
								0.00	0.00	30.75	9.0	
5	Automatic		20	120'-0"	3'-2"	7.9	60	0.00	0.00	57.25	1.0	do
6	Hand	Wide open	2	130'-0"	4'-0"	12.5	60	0.00	0.00	60.00	0.0	do
7	do	do	1	128'-0"	5'-0"	19.6	60	0.00	0.00	60.00	0.0	do
8	do	do	4	80'-0"	3'-2"	7.9	60	0.00	0.00	56.25	1.3	do
								8.25	5.25	0.00	51.0	do
9	Automatic		5	150'-0"	4'-6"	16.0	60	5.25	13.75	0.00	40.0	do
10	do		2	90'-0"	3'-6"	9.6	60	0.00	0.00	39.25	8.0	do
11	Hand	Wide open	1	105'-0"	5'-0"	19.6	60	0.00	0.00	60.00	0.0	do
12	do	½ open	1	125'-0"	3'-6"	9.6	60	0.00	0.00	57.50	0.2	do
13	Automatic		1	340'-0"	10'-6"	86.5	60	0.00	2.00	8.75	20.7	do
14	Hand	⅔ open	1	150'-0"	10'-0"	78.5	60	0.00	0.00	60.00	0.0	do
15	do		1	376'-0"	4'-0"	12.6	60	0.00	0.00	59.50	0.3	do
16	do	¼ open	1	240'-0"	3'-0"	7.1	60	0.25	5.25	24.50	18.7	do
17	Automatic		1	300'-0"	4'-0"	12.6	60	0.00	0.00	57.00	1.2	do
								0.00	0.00	8.75	17.3	
18	Hand	⅓ open	2	220'-0"	12'-0"	113.0	60	0.00	2,75	3.25	27.8	do
19	do	Wide open	1	100'-0"	7'-0"	38.8	60	0.00	0.50	39.50	9.3	Light
					4'-0"	12.6						
20	do	do	2	120'-0"	5'-0"	19.6	60	0.00	0.00	17.25	9.0	Normal
21	do	do	2	120'-0"	3'-0"	7.1	60	0.00	0.00	54.50	1.0	do
22	do	do	8	170'-0"	6'-0"	28.3	60	0.00	0.00	11.50	16.9	do
23	do	do	1	165'-0"	4'-6"	16.0	60	0.00	0.00	60.00	0.0	do
24	Automatic	Open or 45°	26	115'-0"	3'-0"	7.1	60	0.00	0.00	60.00	0.0	do
25	do	do	8	115'-0"	3'-6"	9.6	60	0.00	0.25	39.00	10.0	do

26	do	....	14	120'-0"	3'-6"	9.6	60	0.00	1.00	0.75	27.6	do
27	do	....	8	120'-0"	3'-6"	9.6	60	1.25	0.75	10.00	19.8	do
28	do	....	18	115'-0"	3'-0"	7.1	60	0.00	0.00	60.00	0.0	do
29	do	....	10	115'-0"	3'-0"	7.1	60	0.00	0.00	60.00	0.0	do
30	Hand......	Wide open.........	5	70'-0" 75'-0"	....	....	60	0.00	0.00	60.00	0.0	do
31	Automatic	....	1	....	....	....	60	0.00	0.00	39.00	6.0	do
32	do	....	16	120'-0"	3'-6"	9.6	60	0.00	0.50	26.25	15.0	do
33	do	....	3	150'-0"	6'-0"	28.3	60	11.00	16.00	0.25	42.0	do

TABLE 5—*Detail of data taken on plants equipped with chain-grate stokers*—Continued.

No. of Installation.	Remarks.
1	Good equipment, fairly well installed and operated, general plant conditions poor.
2	Good equipment, properly installed and fairly well operated. General plant conditions poor.
3	Not much care used in operation, surrounding and plant conditions poor.
4	Plant conditions poor and not much care used in operation. Good equipment.
5	Plant conditions and operation good. Good equipment.
6	Plant conditions and operation good. Good equipment, properly installed.
7	Operating conditions poor, but plant is fairly well operated. Good equipment.
8	Plant conditions and method of operation good.
9	Good equipment, properly installed and well operated.
10	Plant conditions good. Installation properly made and well operated.
11	Good equipment, not properly installed and poorly operated.
12	Good equipment, properly installed and operated. Plant conditions fair.
13	Automatic damper in stack, hand dampers on boilers ⅔ open. Good equipment, properly installed, fairly well operated.
14	General plant conditions very good. Good equipment, properly installed and well operated.
15	Plant conditions poor. Good equipment, fairly well operated.
16	Space very much limited, equipment crowded into too limited space, well operated.
17	Good equipment, properly installed and well operated.
18	Working conditions fair, equipment properly installed and well operated.
19	Plant conditions fair. Equipment properly operated.
20	Working conditions fair. Equipment fairly well operated.
21	Equipment properly installed and fairly well operated.
22	General plant conditions fair. Good equipment and very well operated.
23	Boiler room dark and dirty. Equipment properly installed and fairly well operated.
24	Dark and dirty boiler room, operating conditions poor. Equipment properly installed, fairly well handled.
25	Operating and surroundings conditions poor. Old equipment, fairly well installed and operated.
26	Boiler room very well lighted but dirty. Fairly well operated.
27	Operating conditions fair, moderate amount of care used in handling fires.
28	General plant conditions good but only moderate amount of care exercised in operation.
29	Equipment properly installed, only moderate amount of care exercised in handling. Boiler room dark and dirty.
30	Good equipment but only moderate amount of care used in operation. General plant conditions good.
31	Boiler equipment with Wooley furnace. Breeching long and tortuous.
32	Boiler room dark and dirty. Equipment fairly well installed and operated.
33	General plant conditions poor. Operation fair and equipment in fair condition.

Results of Survey of Chain-grate Stoker Plants.

Examinations were made of thirty-three plants in which the chain-grate stoker is installed. Pittsburgh coal was used in all of the plants, slack, or nut and slack being used in twenty-three plants and crushed run of mine in ten plants. Horizontal water tube boilers were installed in twenty-three plants and vertical water tube boilers in ten plants. The plants varied in size from 250 to 6,500 boiler horse power, and they contained from one to twenty-six boilers per plant. The thickness of the fire varied from 4 to 8 inches. Natural draft was used in all but one plant, where induced draft was supplied. The draft in the furnace at twenty-five plants varied from 0.12 to 0.40 inches of water; at the rear of the boiler in eight plants from 0.20 to 0.53 inches of water; in the breeching at five plants from 0.38 to 0.80 inches of water; and at the base of the stack in thirteen plants from 0.40 to 0.95 inches of water. Steady loads were carried by eight plants, and variable loads by thirty-three plants.

Observations were made upon thirty-six stacks connected to boilers equipped with chain-grates with the following results:

The average of these observations show 2.1 minutes per hour of smoke equal to or greater than 60 per cent. black, 37.6 minutes per hour when no smoke issued from stack and an average percentage of 10.5 black smoke from observations. Observations of this same class show a maximum of 27.0 minutes per hour and a minimum of 0.00 minutes per hour smoke equal to or greater than 60 per cent. black; maximum of 60.0 minutes and minimum of 0.00 minutes per hour clean stack; and a maximum of 51.0 per cent. and a minimum of 0.00 per cent. black smoke from observations.

Front-feed Stokers.

There are several types of stokers now on the market employing this principle of feeding coal. They differ mainly in the manner of handling the fuel in the furnace

and the method of getting rid of the ash and clinker. The type encountered in most installations, and which probably has been developed to a greater extent than any other, now on the market, is illustrated by Figure 33. In this type the coal is fed from the hopper, placed at the front of the furnace, by means of a pusher plate actuated through an agitator sector, these sectors are in turn operated by eccentrics connected to a shaft and driven through a set of gears by means of an engine or motor.

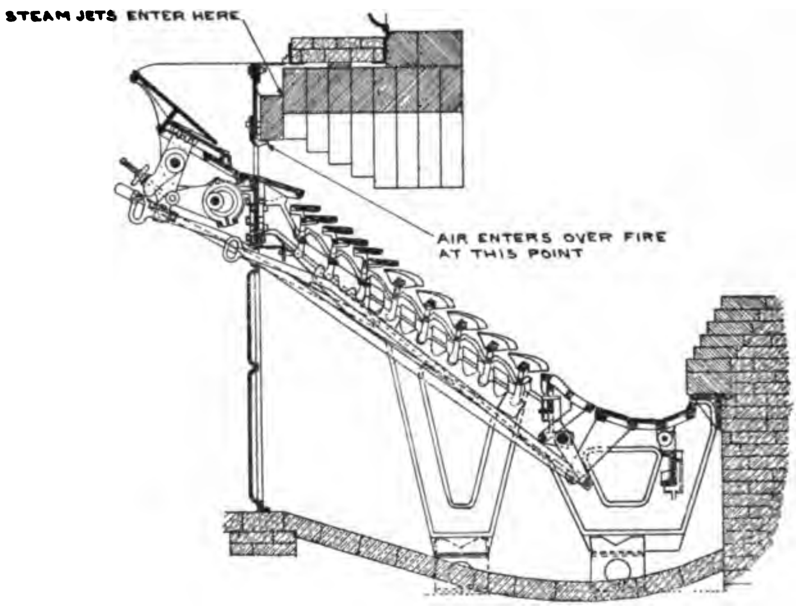

Figure 33—Detailed construction of Roney stoker.

The stroke of this agitator sector is varied by means of a hand wheel that can be screwed on or off a stud, which is connected to the eccentric strap of the stoker shaft. By varying the position of this hand wheel the stroke of the pusher plate and consequently, the amount of coal fed to the furnace is varied. The coal is fed onto a flat plate called a dead or coking plate, where it is first ignited by the heat from an arch which is sprung over the entire width of the furnace. The length of this arch varies con-

siderably in different installations. Present tendency is to construct this arch long enough to cover almost the entire furnace, and extend the furnace well beyond the front of the boiler.

Air and steam are usually admitted over the fire immediately over the dead or coking plate as shown in the illustration. The ignited fuel is pushed from this coking plate by the fresh fuel entering the furnace, onto the corrugated set of grate bars placed at the upper part of the furnace. Here it is completely coked, then it is fed onto a second set of grate bars containing more air space per square foot of grate surface. The rocker bar, that moves or rocks the grates, is so designed that the amount of motion it imparts increases from the top to the bottom of the grate. The fuel is practically consumed by the time it reaches the end of these grates, and is now fed onto the dump grate, from which the ash and clinker is dropped periodically from the furnace. In order that the partly consumed fuel shall not be dumped into the ash pit, a guard is provided which will, when raised, hold this fuel back during the dumping process. In the earlier types of this stoker a single pusher plate, the entire width of the furnace, was provided for feeding the coal. Difficulties were encountered with this type on account of a lack of control that could be exercised in order to keep the grates evenly covered. Changes have been made in the design and now four pusher plates are usually provided with each furnace, the length of stroke of each being separately controlled. This allows considerable latitude in the control of the fuel bed along the lines just mentioned.

The ease of access to the fuel bed, and the ease with which this type of stoker may be made to pick up sudden changes in load has subjected it to considerable abuse in handling. The present tendency to set these stokers with longer arches is much to be commended, the short arch allowing insufficient coking area, and thus permitting green fuel to be moved to the lower grates where its combustion is a source of smoke production. Also, when set

with a short arch, the distance from the fuel bed to the tubes is much too short, and the combustion space too much restricted to allow either space or time for complete combustion of the volatile gases. Care must be exercised in handling this type of stoker in order to keep the fuel bed evenly covered or the coal will avalanche and burn with the production of large quantities of smoke. This is especially true when this stoker is set with a short arch, and a fire carried that is too thin or is allowed to

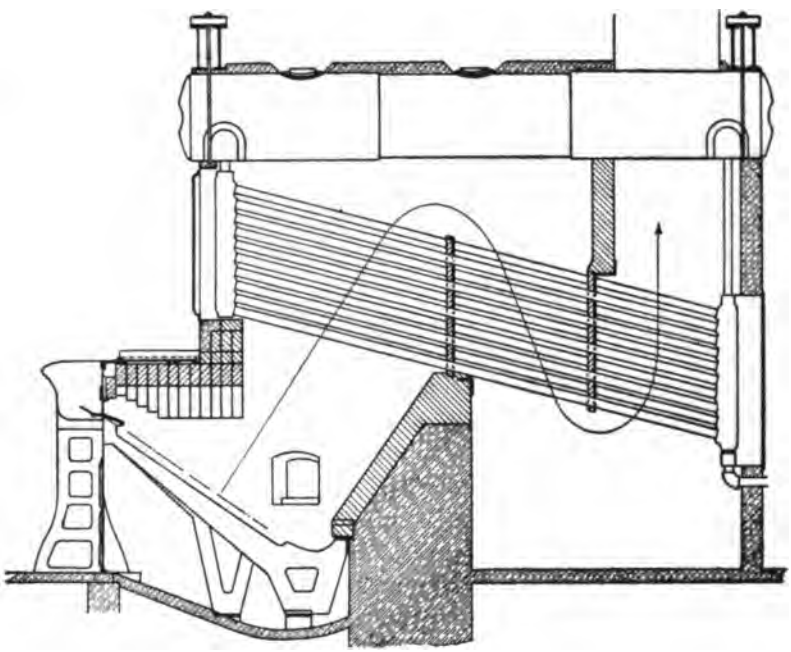

Figure 34—Front-feed stoker, Roney model, as applied to Babcock & Wilcox water-tube boiler.

burn into holes. Considerable care must be exercised in cleaning the fire, or loss of considerable unburned fuel to the ash pit will result, and large amounts of smoke will be made due to the avalanching of the entire fuel bed. When operated at high ratings, unless provided with some special type of setting where ample provisions of refractory surface is made, this type usually causes some smoke.

This, however, may be kept down to some extent by increased care in operation.

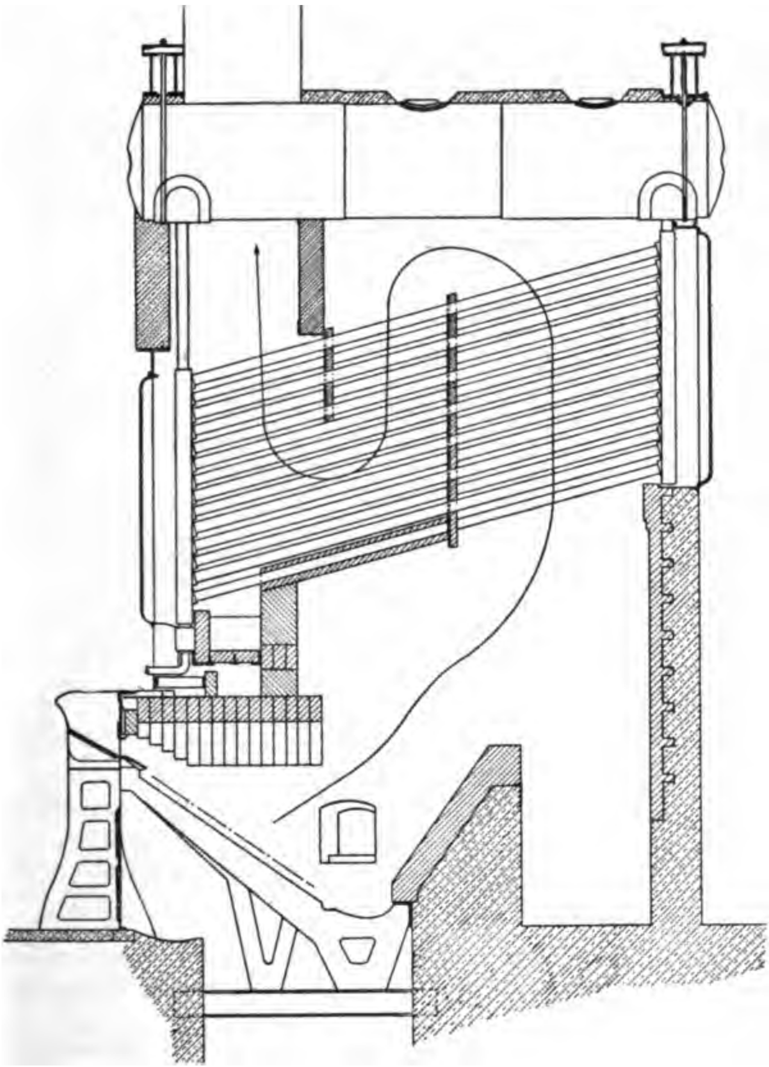

Figure 35—Front-feed stoker, Roney model, as applied to Babcock & Wilcox water-tube boiler, Alert type of setting.

Figure 34 illustrates this type of stoker, Roney Model, as usually applied to a B. & W. water tube boiler. The

distance of the tubes from the fire in this setting is rather short, and the combustion space somewhat restricted to allow proper length of time for mixing the air and volatile gases. With the proper care in operation, however, this boiler will operate considerably in excess of rating without the production of black smoke.

Figure 35 illustrates this type of stoker, Roney Model, as applied to a B. & W. boiler with Alert type of setting. Provision is made for ample refractory surface and large combustion chambers, both of which are much to be com-

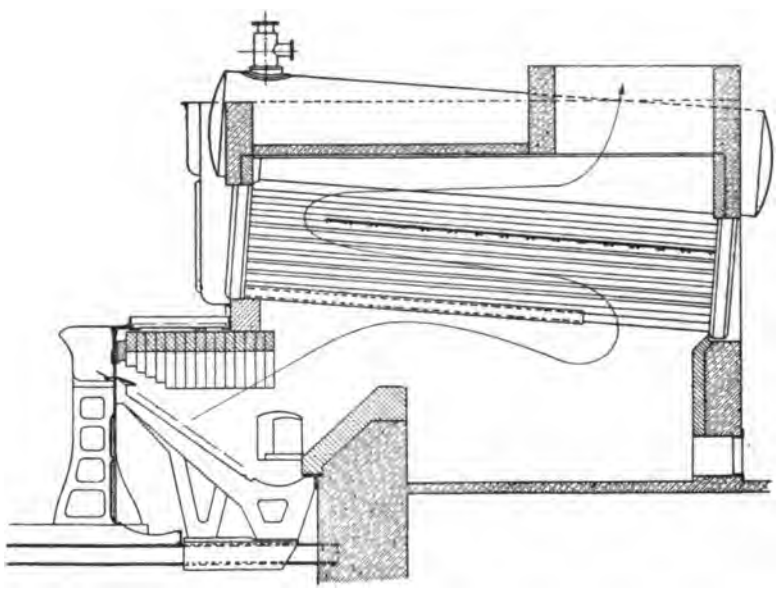

Figure 36—Front-feed stoker, Roney model, as applied to Heine water-tube boiler.

mended. This type of setting should develop capacities far in excess of rating, without the production of smoke, if reasonable care is exercised in handling.

Figure 36 illustrates this type of stoker, Roney Model, as applied to a Heine water tube boiler having a fire tile roof made by encasing the lower row of tubes in first tile. Provision is also made in this setting to obtain a larger coking area per square foot of grate surface. The fire

tile roof serves to keep the combustible gases at a high temperature.

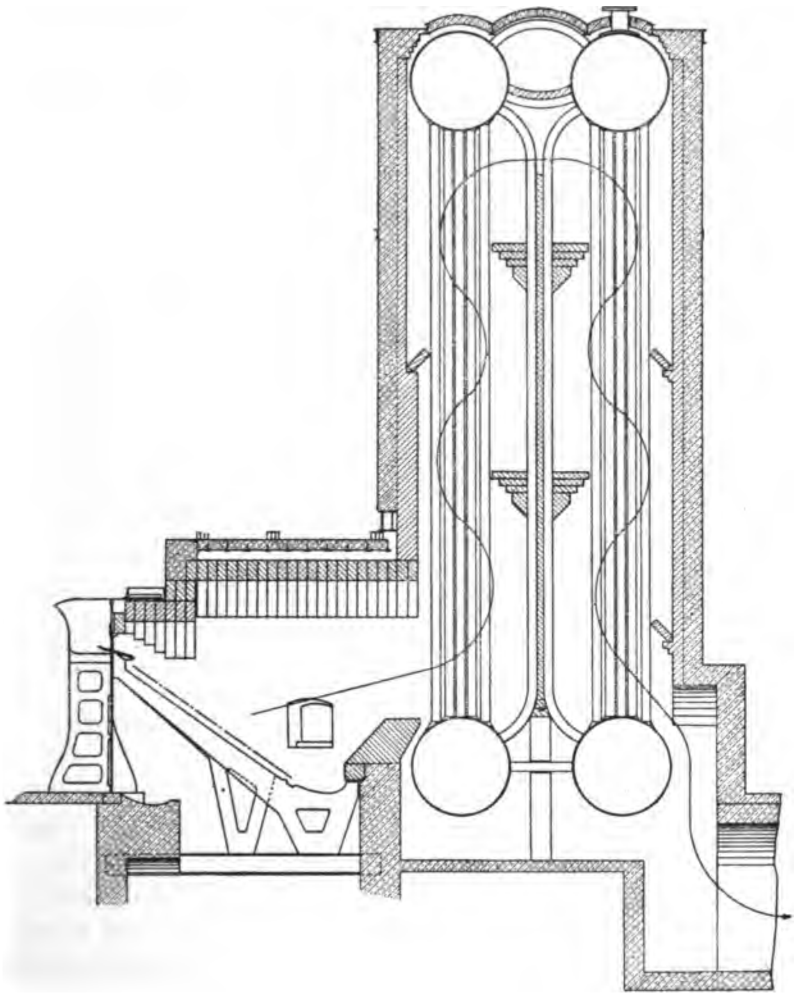

Figure 37—Front-feed stoker, Roney Model, as applied to a Rust, vertical water-tube boiler.

Figure 37 illustrates this type of stoker, Roney Model, as applied to a Rust vertical water tube boiler. This setting is characterized by large coking area per square foot

of grate surface. The distance from the fire to the tubes, and the size of the combustion chamber is, however, somewhat restricted.

Figure 38 shows a front-feed stoker, Roney Model, as applied to a horizontal return tubular boiler.

Figure 39 shows a front-feed stoker, Roney Model, as applied to a Stirling Boiler.

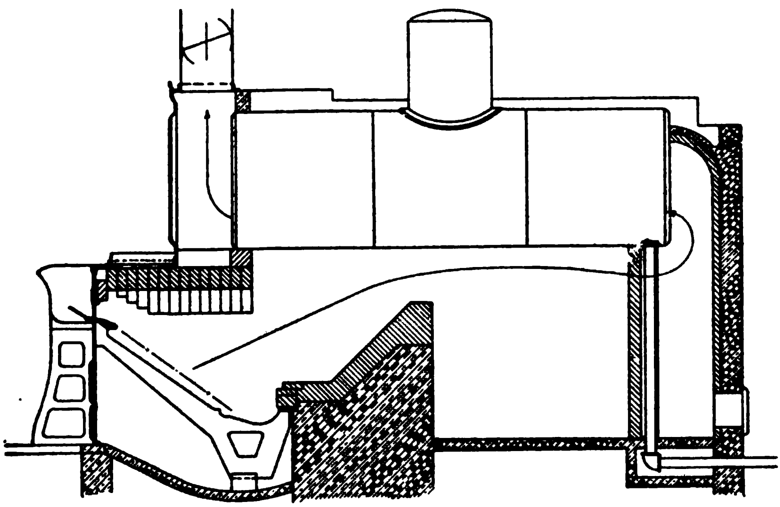

Figure 38—Front-feed stoker, Roney model, as applied to horizontal return tubular boiler.

Figure 40 represents front-feed stokers, Roney Model, as applied to Stirling Boilers at Delray Station of the Detroit Edison Company at Detroit, Michigan. These boilers are equipped with very large combustion chambers which permit of a thorough mixing of the gases and allow ample time for combustion to take place before the gases are cooled below their ignition temperature. Using a high grade, high volatile fuel, remarkable results have been obtained with these units, and little difficulty is encountered in eliminating smoke.

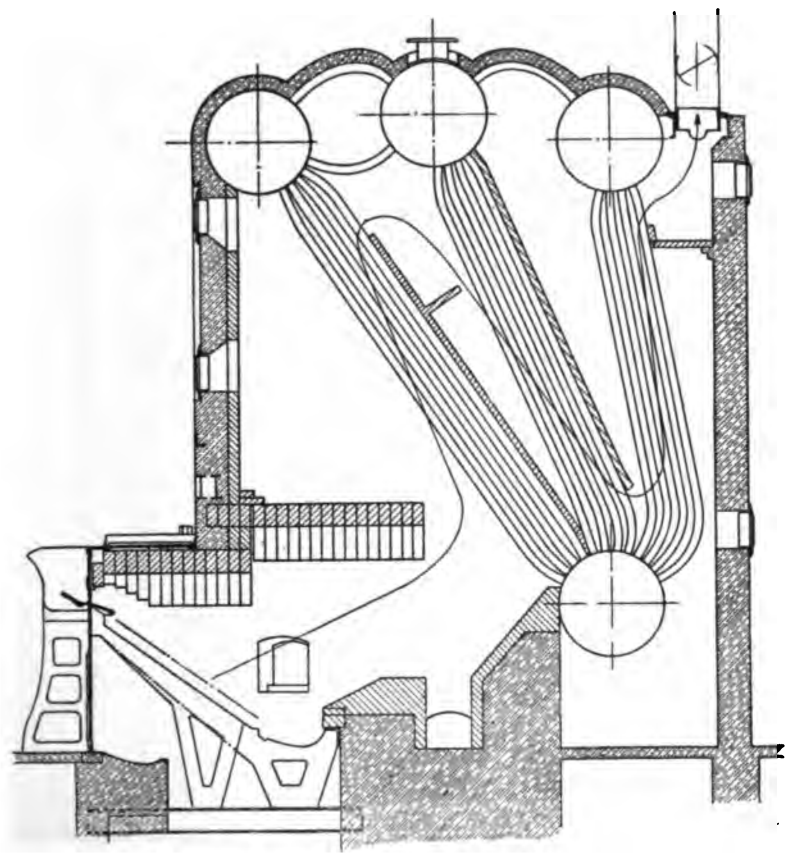

Figure 39—Front-feed stoker, Roney model, as applied to Stirling water-tube boiler.

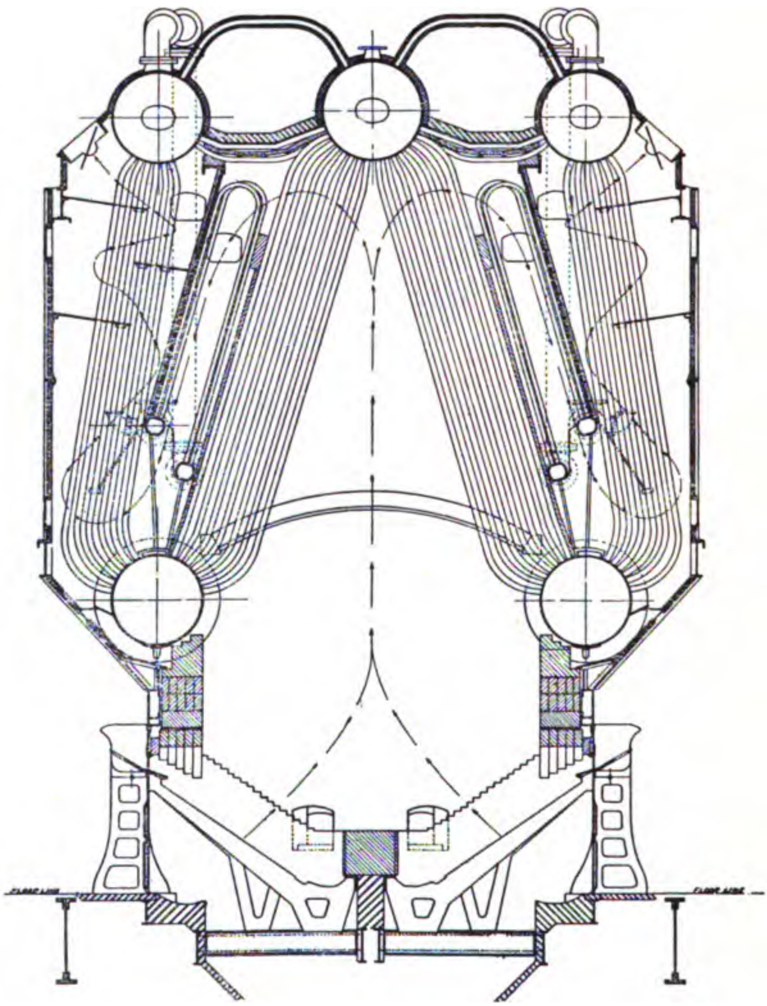

Figure 40—Front-feed stoker, Roney model, as applied to large Stirling water-tube boilers.

TABLE 6—*Detail of data taken on plants equipped with front-feed stokers.*

No. of Instal-lation	Coal: Commercial Name	Coal: Size	Coal: Quantity per yr. Tons	Stoker: Kind of Stoker	Stoker: Thickness of Fire Inches	Stoker: Frequency of Cleaning	Furnace: No.	Furnace: Grate Area Sq. Ft.	Dimensions Feet and inches. Grate to H. S.: Aver.	Grate to H. S.: Min.	Width	Length	Front Furnace to Front Boiler	Height Coking arch: Front	Height Coking arch: Back	Length Coking Arch	Height Arch Rear Furnace
1	Pittsburgh	Slack	110,000 180,000	Roney	4-7	2 in 5 hrs	22	8-78 14-56	9'-0"	......	......	......	......	1'-0"	5'-0"	......	4'-0"
2 (a)	do	Crushed Run of Mine		Old Model Roney	4-6	6 " 24 "	2	93.6	......	......	11'-0"	8'-8"	0	......	......	......	......
(b)	do	do	91,000	do	4-6	6 " 24 "	6	86.0	......	......	12'-6"	7'-2"	0	......	......	......	......
(c)	do	do	Total	do	4-6	6 " 24 "	5	68.2	......	......	9'-0"	7'-8"	......	......	......	......	......
(d)	do	do	for all	do	4-6	6 " 24 "	3	62.0	......	......	9'-0"	7'-2"	......	......	......	......	......
(e)	do	do	plants	do	4-6	6 " 24 "	2	62.0	......	......	9'-0"	7'-2"	......	......	......	......	......
(f)	do	do		do	4-6	6 " 24 "	1	53.0	......	......	7'-9"	7'-2"	......	......	......	......	......
3	do	do	......	Roney	3-24	2-4 " 24 "	4	87.8	8'-0"	......	9'-6"	9'-3"	0	......	......	......	......
4 (a)	do	Slack	......	do	6-8	......	2	45.5	8'-6"	7'-6"	7'-0"	6'-6"	0	......	......	......	......
(b)	do	do	......	do	6-8	......	4	45.5	8'-6"	7'-6"	7'-0"	6'-6"	0	......	......	......	......
(c)	do	do	......	do	6-8	......	3	47.7	8'-6"	7'-6"	6'-10"	7'-0"	0	......	......	......	......
(d)	do	do	......	do	6-8	......	4	52.5	8'-6"	7'-6"	7'-0"	7'-6"	0	......	......	......	......
(e)	do	do	......	do	6-8	......	2	53.6	8'-6"	7'-6"	7'-8"	7'-0"	0	......	......	......	......
5	do	do	7,500	do	4-5	2 " 24 "	8	68.0	7'-6"	5'-6"	10'-0"	7'-0"	8'-8"	1'-3"	3'-0"	3'-0"	5'-3"
6	do	do	......	Brightman	6	6 " 24 "	4	54.8 32.2	7'-6"	5'-6"	9'-5" 4'-6"	5'-9" 7'-2"	0	2'-6"	6'-0"	6'-6"	4'-0"
7	do	do	68,000	Roney	5	4 " 12 "	5	59.4	......	......	7'-9"	7'-8"	0	1'-8"	2'-0"	4'-8"	......
8	do	do		do	8	6 " 24 "	5	49.0	18'-0"	......	7'-4"	6'-8"	4'-0"	7"	3'-6"	6'-8"	......
9	do	do	10,000	do	4-5	2 " 24 "	6	50.0	......	......	8'-4"	6'-0"	0	1'-0"	1'-6"	2'-6"	......
10	do	do	3,000	New Model Roney	4-6	6 " 24 "	2	34.8	5'-0"	4'-0"	6'-3"	5'-6"	0	10"	3'-0"	3'-0"	......
11	do	do	3,100	Old do do	4	2-5 " 24 "	3	49.0	......	......	7'-0"	7'-0"	0	1'-2"	3'-0"	2'-4"	......
12	do	do	11,200	Roney	4	3 " 24 "	3	60.4	14'-0"	12'-0"	8'-4"	7'-8"	1'-6"	1'-0"	3'-9"	4'-3"	......
13	do	do	2,400	do	3	5 " 24 "	3	30.0	6'-6"	4'-6"	4'-0"	7'-6"	3'-0"	10"	4'-0"	3'-0"	......
14	do	Nut & Slack	23,000	do	4	4 " 24 "	5	66.7	12'-0"	10'-0"	8'-4"	8'-0"	0	10"	1'-8"	1'-6"	......
15	do	Nut	4,300	do	4	6 " 24 "	2	42.0	7'-6"	6'-6"	6'-0"	7'-0"	6½"	1'-6"	2'-6"	2'-0"	6'-0"
16	do	1¼ Slack	......	do	4-5	4 " 24 "	13	50-75 100-130	......	......	......	......	......	......	......	......	......

17	do	Slack	3,300	New Model Roney	5-6	3 " 24 "	8	32.4	6'-0"	....	7'-4"	4'-5"	1'-0"	1'-3"	3'-0"	3'-0"	....
18	do	do	36,000	Old do	8	6 " 24 "	8	69.5	5'-6"	5'-0"	8'-4"	8'-4"	0	1'-0"	4'-0"	5'-4"	....
		Crushed Run of														3'-0"	
19	do	Mine & Slack	76,100	do	4-6	6 " 24 "	18	51.0	5'-0"	4'-6"	8'-0"	6'-6"	0	1'-2"	3'-0"	2'-0"	....
20	do	do	29,530	Roney	4-6	4 " 24 "	18	50.0	14'-0"	12'-0"	8'-4"	6'-0"	0	1'-2"	3'-0"	2'-0"	....
								60.0			7'-6"	8'-0"					
21	do	Slack	21,000	do	3-4	6 " 24 "	5	36.0	....	....	6'-0"	6'-0"	0	1'-3"	....	2'-0"	....
		Crushed															
22	do	Run of Mine	18,191	do	4-6	4 " 24 "	4	48.0	....	....	8'-0"	6'-0"	1'-6"	1'-3"	1'-9"	2'-6"	....
				4 Roney													
23	do	do	26,651	8 Brightman	5-6	4 " 24 "	12	48.0	....	....	8'-0"	6'-0"	1'-0"	1'-6"	2'-6"	2'-0"	....
24	do	do	15,129	Roney	4-6	4 " 24 "	4	48.0	....	....	8'-0"	6'-0"	1'-0"	1'-6"	2'-6"	1'-6"	....
																1'-6"	
25	do	do	60,518	do	4-6	4 " 24 "	4	48.0	....	....	8'-0"	6'-0"	0	1'-3"	2'-6"	2'-0"	....
																1'-6"	
26	do	do	31,275	do	4-6	4 " 24 "	16	48.0	....	....	8'-0"	6'-0"	0	1'-6"	2'-6'	2'-0"	....
																1'-6"	
27	do	do	10,425	do	4-6	4 " 24"	4	48.0	....	....	8'-0"	6'-0"	0	1'-6"	2'-6"	2'-0"	....
28	do	do	12,250	do	4-6	4 " 24 "	4	48.0	....	....	8'-0"	6'-0"	12"	1'-6"	2'-6"	3'-0"	....
29	do	Slack	14,400	do	7-8	5 " 24 "	6	50.0	6'-0"	4'-0"	8'-4"	6'-0"	7'-6"	8"	1'-6"	1'-8"	....
		Crushed															
30	do	Run of Mine	....	do	4-5	6 " 24 "	2	....	....	....	10'-0"	7'-0"	....	1'-6"	3'-3"	3'-3"	....
31	do	Slack	12,600	do	4-5	5 " 24 "	4	69.4	6'-0"	4'-0"	10'-9"	6'-5"	....	9"	1'-10	2'-6"	....
32	do	do	26,700	do	4-6	5 " 24 "	4	60.0	....	....	10'-0"	6'-0"	0	....	....	5'-0"	....
33 (a)	do	¾ Nut & Slack	....	New Model Roney	5-7	6 " 24 "	6	80.5	....	....	10'-3"	7'-10"	1'-6"	....	....	3'-6"	....
(b)	do	do	108,000	Old do	5-7	6 " 24 "	10	72.0	....	....	10'-3"	7'-0"	1'-6"	....	....	3'-6"	....
(c)	do	do		New do	5-7	6 " 24 "	2	91.2	....	....	10'-3"	8'-10"	1'-6"	....	....	6'-0"	....
34	do	2" Nut & Slack	95,000	do	6-8	Varies	10	111.5	8'-0"	....	12'-0"	9'-3"	5'-3"	12"	6'-6"	7'-0"	....

TABLE 6—*Detail of data taken on plants equipped with front-feed stokers*—Continued.

No. of Instal-lation	Boilers						Load		
	Type	Builders Rated H. P.	No. Instal-led.	No. used to carry		Steam Pressure Lbs. per sq. in.	Requirement	Nature	Character
				Aver. Heavy Load	Aver. Light Load				
1	B. & W. Water Tube	6,300	22	20	14	150	Power	Variable	Power & Light
2 (a)	Cahall do	1,020	2	2		115	do	Uniform	Mill
(b)	Cahall do	2,535	6	5		115	do	do	do
(c)	Heine do	2,675	5	4		115	do	do	do
(d)	Heine do	900	3	3		115	do	do	do
(e)	National do	600	2	2		115	do	do	do
(f)	Heine do	250	1	1		115	do	do	do
3	B. & W. do	1,600	4			150	do	Variable	do
4 (a)	B. & W. do	528	2			135	do	do	do
(b)	Stirling do	1,000	4			150	do	do	do
(c)	Stirling do	600	3			125	do	do	do
(d)	Atlas do	1,000	4			120	do	do	do
(e)	Geary do	500	2			120	do	do	do
5	Rust do	2,680	8	8		150-160	do	Variable	do
6	Stirling do	1,200	4	4		135	do	do	do
	Horizontal do 4 B. & W.	1,000	5	5		100	Power & heat	do	Factory
7	1 Heine do	1,190	5			100	do	do	do
8	B. & W. do	1,500	6			120	Power	do	do
9	Geary do	450	2	1		90-100	Power & heat	do	do
10	Erie City do	750	3			100	do	do	do
12	Heine do	948	3	2	2	125	do	Variable	Building
13	B. & W. do	300	3	1	1	125	do	do	do
14	B. & W. do	1,500	5	5	4	125	do	do	do
15	Stirling do B. & W.	500	2	1	1	155	do	Uniform	do
16	Munoz do	4,675	13	11-12		140	Power, heat & light	do	Power
7	Aultman & Taylor do	675	3	2		130	Power	Variable	Bldg.

18	B. & W. do	2,400	8	7	5	160	Power & heat.........	Variable.........	do
19	B. & W. do	5,000	20	18	....	150	Power.........	Uniform.........	Mfg.
20	B. & W. do	4,500	18	13-13	....	150	do	do	do
21	Erie City do	1,600	5	4	4	125	do	do	do
	2 Aultman, Taylor								
22	2 B. & W. do	1,000	4	4	....	120-125	do	Fairly Uniform.........	Pumping
23	B. & W. do	3,000	12	11	....	120-125	do	Variable.........	Mill
24	Aultman, Taylor do	1,000	4	3	....	120-125	do	do	do
	12 B. & W.								
25	4 Aultman, Taylor do	4,000	16	14	....	120	do	do	do
	B. & W. &								
26	Aultman Taylor do	3,000	12	12	....	110-120	do	do	do
27	Aultman Taylor do	1,000	4	4	....	110-120	do	do	do
28	B. & W. do	1,000	4	4	....	110-120	do	do	do
29	Cahall do	1,500	6	5	....	140	Power & heat.........	do	Mfg.
30	Erie City do	650	3	3	....	140	Power.........	Variable.........	Mill
31	Stirling do	1,200	4	3	....	125	Power & heat.........	do	Power
32	Stirling do	1,200	4	3	....	140	Power.........	do	Mill
33 (a)	B. & W. do	2,250	6	5	2	150	do	do	Power
(b)	B. & W. do	3,750	10	9	4	150	do	do	do
(c)	B. & W. do	750	2	2	2	150	do	do	do
34	B. & W. do	6,000	10	8	....	165	do	do	do

TABLE 6—*Detail of data taken on plants equipped with front-feed stokers*—Continued.

No. of Installation	Rating: Average Load. Heavy: Hrs. per day	Heavy: Coal per day (tons)	Light: Hrs. per day	Light: Coal per day (tons)	Draft: Kind	Inches of Water: Furnace	Rear of Boiler	Breeching	Base of Stack	Conditions Under Which taken	Breeching: Distance Stack to nearest boiler Feet.	Size Feet	Where measured.	No. of Ells.
1	2-7				Natural	0.3-0.5			1.00					1
2 (a)	24				do	0.2-0.3		0.90	0.90		10'-0"	4'-6"x6'-6"	At Stack	1
(b)	24				do							4'-0"x6'-0"		1
(c)					do									
(d)					do									
(e)					do									
(f)					do									
						0.15	0.40					3'-6"x5'-0" to		2-90°
3	24				do	0.35	0.50		1.00		21'-0"	10'-0"x5'-6"	Each end	1-45°
						0.20								
4 (a)	24				do	0.23								
						0.18								
(b)	24				do	0.26								
						0.12								
(c)	24				do	0.22								
						0.11								
(d)	24				do	0.15								
(e)	24				do									
5	24		24		do	0.48					8'-6"	15.5 sq. ft.		0
6	24				do	0.15						10'-3"x1'-6"		0
						0.08								
7	24				do	0.20					15'-0"	4'-0" dia.		
						0.15								
8	12				do	0.45				Normal				3
						0.20							Between	
9	12				do	0.30					15'-0"	5'-6"x9'-8"	1 & 2 stack	1
10	12	30-35			do	0.20								1
11	24	9.0			do	0.25			0.75		12'-0"	4'-3"x5'-0"	Near stack	2
												5'-0" dia.		
12	12	21.0	12	10	do	0.20			1.00		89'-0"	6'-0" do		3
13	10		14	25	do						18'-0"	3'-0"x3'-6"		2-45°

14	10	45.0	14		do						12'-0"	7'-0"x8'-0"		0
15	8	7.0	16	4.5	do	0.20	0.88				15'-0"	4'-0"x5'-0"	Near stack	0
						0.10	0.15							
16	5		19		do	0.29	0.46		0.75		6'-0"			1
											60'-0" to			
17	24	25-30	24	10-15	do	0.08			0.43		70'-0"	5'-0"x6'-0"	Near Stack	2
18	24				do	0.50		1.30	1.30		50'-0"	6'-0"x6'-0"	At one end	2
												5'-0" dia.		
19	24	250.0			do						25'-0"	4'-6"x5'-0"	At boiler	1 to 2
20	24	98.0			do	0.16		1.00			6'-0"			
21	24	70.0			do	0.25								0
22	24	50.0			do	0.40			0.80		At boiler	3'-0"x3'-6"	At boiler	1
						0.20			0.70					
23	24	73.3			do	0.30			0.70		do	3'-0"x3'-6"		1
24	24				do	0.25			0.60		do	3'-0"x3'-6"		1
						0.05		0.40			4 At			
25	24				do	0.20		0.50	1.40		boilers	3'-0"x3'-6"		1 & 3
						0.10		0.15			4 At			
26	24	85.8			do	0.25		0.60			boilers	3'-0"x3'-6"		1 & 3
								0.15						
27	24	28.6			do	0.10		0.40			10'-0"	3'-0"x3'-6"		3
28	24	33.6			do	0.10		0.20			30'-0"	3'-0"x3'-6"		3
						0.20								
29	24	48.0			do	0.30								
30	24				do	0.15		0.80						
31	24	35.0			do	0.15		0.80						2
						0.27		0.75						
32	24				do	0.40		0.90				Stacks on	boilers	0
						0.16		0.66						
33 (a)	18				do	0.40		1.00		Normal		do	do	0
						0.28		0.70						
(b)	18	300.0			do	0.32		1.00		do		do	do	0
						0.12								
(c)	18				do	0.30		1.00		do		do	do	2
						0.16								
34	7				do	0.35		0.75		do	4'-0"			1

TABLE 6—*Detail of data taken on plants equipped with front-feed stokers*—Continued.

No. of Instal-lation	Dampers: Kind	Dampers: Usual position	Stack: No.	Stack: Height Feet	Stack: Size Feet	Stack: Area Square Feet	Smoke Records: Total mins. of obser-vation	Smoke Records: Mins. in one hr. of 100 to 80 %	Smoke Records: Mins. in one hr. of 80 to 60 %	Smoke Records: Mins. in one hr. of Stack Clean	Smoke Records: Aver. per cent of Black Smoke	Load during obser-vations.
								6.75	1.25	47.50	12.6	
1	Hand	Wide open	7	150'-0"	7'-0"	38.4	60	14.75	12.00	4.25	43.3	
								13.25	8.50	24.50	31.6	
2 (a)	do	do	1	150'-0"	5'-9"	26.0	60	18.00	14.00	9.00	47.3	
(b)	do	do	3	125'-0"	5'-3"	21.6	60	0.25	5.50	45.75	10.0	
				125'-0"	4'-9"	17.7						
(c)	do	do	2	125'-0"	5'-9"	26.0	60	5.50	3.35	17.50	25.0	
				125'-0"	4'-9"	17.7						
(d)	do	do	2	125'-0"	3'-6"	9.6	60	23.00	8.75	6.50	54.0	
(e)	do	do	1	125'-0"	4'-6"	15.9	60	0.00	0.00	24.75	12.0	
(f)	do	do	On stack (d)									
3	None		1	185'-0"	11'-0"	95.0	60	8.25	19.00	9.25	42.5	
4 (a)	Hand	Wide open	1	127'-0"	5'-0"	19.6	60	2.00	3.00	37.00	13.5	
								5.75	3.00	37.25	17.5	
(b)	do	do	2	132'-0"	5'-0"	19.6	60	19.75	16.75	2.00	53.0	
(c)	do	do	3	82'-6"	3'-10"	11.5	60	0.00	1.00	18.25	16.0	
(d)	do	do	2				60	2.75	0.75	49.25	6.0	
(e)	do	do	2	116'-0"	4'-6"	15.9	60	2.75	0.75	49.25	6.0	
								0.50	0.25	54.00	3.0	
5	Automatic		3	120'-0"	4'-0"	12.6	60	0.25	1.00	53.75	3.3	Light
								6.00	4.50	31.25	20.0	
6	Automatic		4	125'-0"			60	7.75	4.00	33.25	22.0	Very Light
				88'-0"	3'-4"	8.7		7.25	9.25	12.25	34.0	
7	Hand	Wide open	2	80'-0"	3'-0"	7.0	60	3.00	0.75	34.75	16.0	
								0.25	0.75	50.00	4.0	
8	do	do	2	125'-0"	6'-3"	30.7	60	0.00	1.25	0.00	27.0	
								19.60	17.00	15.25	44.0	Readings at
9	Automatic		1	150'-0"	5'-0"	19.6	60	15.40	3.75	13.50	38.0	different times
10	Hand	Wide open	1	70'-0"	4'-0"	12.6	60	0.50	0.00	52.50	3.0	
11	do	do	1	168'-0"	5'-6"	23.7	60	14.00	3.00	14.75	36.0	
12	do	do	1	175'-0"	5'-0"	19.6	60	7.00	17.25	11.50	49.0	
13	Automatic		1	180'-0"			60	0.00	0.25	57.50	1.1	
14	Hand	½ open	1	385'-0"	7'-0"	38.5	60	0.25	2.50	44.65	8.8	
15	do	Wide open	1	167'-0"	4'-3"	14.2	60	20.75	9.50	14.00	44.1	

				6-125'-0"	8'-0"	28.3		1.75	2.50	0.00	27.3	
16	do	do	7	1-150'-0"	8'-0"	50.3	60	20.00	10.50	3.25	51.8	
17	Automatic		1	135'-0"	5'-0"	19.6	60	0.00	0 00	41.25	2.0	Light
					11'-0" bottom							
18	do		1	225'-0"	9'-0" top	63.5	60	2.00	3.75	43.00	12.0	Normal
				125'-0"				45.00	12.50	0.00	51.5	
19	Hand	Wide open	7	150'-0"			60	42.75	12.00	0.00	47.9	do
								0.00	10.00	57.00	1.0	
20	do	do	7	125'-0"	5'-0"	19.6	60	5.00	11.75	0.00	37.0	do
					5'-0"	19.6		9.25	4.50	28.00	26.9	
21	Automatic		5	125'-0"	3'-6"	7.0	60	18.50	26.75	0.25	63.0	do
22	do	Wide open or 45°	4	115'-0"	3'-6"	9.6	40	12.00	4.00	11.00	42.8	do
23	do	do	12	115'-0"	3'-6"	9.6	60	0.00	0.25	17.25	15.0	do
24	do	do	4	120'-0"	3'-6"	9.6	60	5.25	2.25	30.25	18.8	do
				4-125'-0"	3'-6"	9.6						
25	do	do	5	1-175'-0"	10'-0"	87.5	60	13.50	5.00	8.00	38.7	do
				4-120'-0"	3'-6"	9.6						
26	do	do	6	2-150'-0"	8'-0"	28.3	60	0.25	1.75	12.25	23.0	do
27	do	do	1	150'-0"	6'-0"	28.3	60	7.50	20.75	0.00	52.5	do
28	do	do	1	150'-0"	6'-0"	28.3	60	1.00	2.25	0.00	27.3	do
								8.25	1.50	26.00	25.0	
29	Hand	Varied	6	90'-0"	3'-0"	7.0	60	1.75	1.25	43.00	7.6	
				119'-0"	4'-0"	12.6		5.50	4.75	29.00	22.0	
30	None		2	100'-0"	4'-6"	15.9	60	23.75	4.00	20.00	47.0	
31	do		1	200'-0"	6'-0"	28.3	60	2.75	6.50	0.00	37.0	
32	Automatic		4	120'-0"	4'-6"	15.9	60	7.00	5.00	35.75	28.0	Normal
								2.25	5.25	16.50	23.0	
33 (a)	do		3	155'-0"	5'-6"	23.7	60	8.75	5.00	22.00	29.0	do
								11.25	1.50	24.25	28.0	
(b)	do		5	155'-0"	5'-6"	23.7	60	8.00	5.25	14.00	29.0	do
(c)	Hand		1	155'-0"	5'-6"	23.7	60	5.25	5.25	18.75	34.0	
34	do	Varied	5	170'-0"	7'-0"	38.5	60	3.50	29.50	0.00	52.0	do

TABLE 6—*Detail of data taken on plants equipped with front-feed stokers*—Continued.

No. of Installation.	Remarks.
1	Old equipment, undergoing extensive repairs. Not much care used in handling fires. Surrounding conditions fair.
2 (a)	Good equipment, some parts properly installed, not much care exercised in firing. Working conditions poor and boiler room dark.
(b)	
(c)	
(d)	
(e)	
(f)	
3	Good equipment but not installed so that it lends itself to smokeless operation without the exercise of considerable care.
4 (a)	Equipment and manner of installation, in this plant, varies from fair to ordinary. Operating conditions and method of handling vary in same proportions.
(b)	
(c)	
(d)	
(e)	
5	Operating conditions and equipment good. Boilers operated far below rating.
6	Good equipment but poorly installed and operated. Operating conditions poor and firing poorly done.
7	Old equipment, poorly installed and operated. Operating conditions poor.
8	New equipment, properly installed and operated.
9	Old equipment, undergoing extensive repairs and renewals. Surrounding and operating conditions good.
10	Good equipment, properly installed and operated. General operating conditions good.
11	Equipment in poor condition, not properly installed or operated. General plant conditions poor.
12	Good equipment set in somewhat restricted space, general conditions good, firing fairly well done.
13	New equipment, proper installed and fairly well operated. General plant conditions good.
14	Good equipment, considerable care exercised in operation.
15	Good equipment, fairly well installed and operated. General plant conditions fair.
16	Old equipment, poorly installed and not much care used in operation. General plant conditions not very good.
17	Good equipment, properly installed and operated. General plant conditions very good.
18	Good equipment, fairly well installed and operated. General plant conditions very good.
19	Equipment poorly installed, not in very good condition and very little care used in operation. General plant conditions good
20	Not much care exercised in operation or installation of this equipment, general plant conditions good.
21	Equipment in fair condition, not much care exercised in operation considerable poking through small doors.
22	Arch very short, considerable poking through small doors in front. General plant conditions good, not much care used in firing.
23	Boilers probably operating far below rating, set with short arches and restricted combustion space, not much care used in firing.
24	Boilers not required to deliver power much in excess of rating. General plant conditions poor, very little care used in firing.
25	General plant conditions good, boilers not properly set and very little care exercised in operation.
26	Dark and dirty plant conditions, boilers not properly set or operated, developing powers not in excess of rating.
27	Operating conditions poor, not much care used, in firing considerable poking through small poke doors.
28	Boilers not properly set, not much care exercised in operation, general plant conditions poor.

29	Equipment properly installed and surrounding conditions good but not much care exercised in operation.
30	
31	Analysis of flue gas showed CO_2-5.2% O-14.6 N-80.2. Probable boiler efficiency 50%.
32	Good equipment fairly well installed and operated, general plant conditions fair.
33 (a)	Good equipment, installation somewhat hampered by restricted space, neccessitating small combustion chambers.
(b)	Considerable poking thru small doors at front of strokers.
(c)	
34	Good equipment but requires exercise of excessive care to operate smokelessly.

Results of Survey of Front-feed Stoker Plants.

Examinations were made of thirty-four plants in which the front-feed avalanche type of stoker was installed. Pittsburgh coal was used in all of the plants. Slack, nut and slack or run of mine and slack was used in twenty-one plants; and crushed run of mine or nut size was used in thirteen plants. Water tube boilers were installed in all of the plants examined, the majority of these being of the horizontal type. The plants varied in size from 450 to 7,980 boiler horse power per plant, and contained from 2 to 22 boilers per plant. The thickness of the fire carried varied from 3 to 24 inches. The draft in the furnace at thirty plants varied from 0.08 to 0.48 inches of water, in the breeching at twelve plants from 0.15 to 1.30 inches of water, at the base of the stack at twelve plants from 0.43 to 1.40 inches of water. Steady loads were carried by eight plants and variable loads by twenty-six plants.

Observations were made upon sixty stacks connected to boilers under which this type of stoker was installed with the following results as regards smoke production:

The average of the observations show 14.6 minutes per hour of smoke equal to or denser than 60 per cent. black, 22.8 minutes per hour when no smoke was omitted from the stacks and an average of 27.2 per cent. black smoke. Observations on this same class show a maximum of 57.50 and a minimum of 0.00 minutes per hour of smoke equal to or denser than 60 per cent. black. A maximum of 57 and a minimum of 0.00 minutes per hour in which no smoke was emitted from stacks; and a maximum of 63 per cent. and a minimum of 1.1 per cent. black smoke.

Side-feed Stokers.

Stokers employing this principle in feeding the fuel have not been subject to as many variations in design as those using the front feed principle, although they have been on the market in this country for many years. The main difference in the construction of the various types of this stoker, as now on the market, is in the method of

feeding the coal and getting rid of the ash and clinker. In this type, at either side of the furnace, and extending its entire length, is a coal magazine, at the bottom of which is the coking plate which supports the upper end of the inclined grates. A coking arch is sprung over the entire furnace, and usually extends well beyond the end of the furnace. This arch is supported on side plates, which form part of the magazine in which the coal is con-

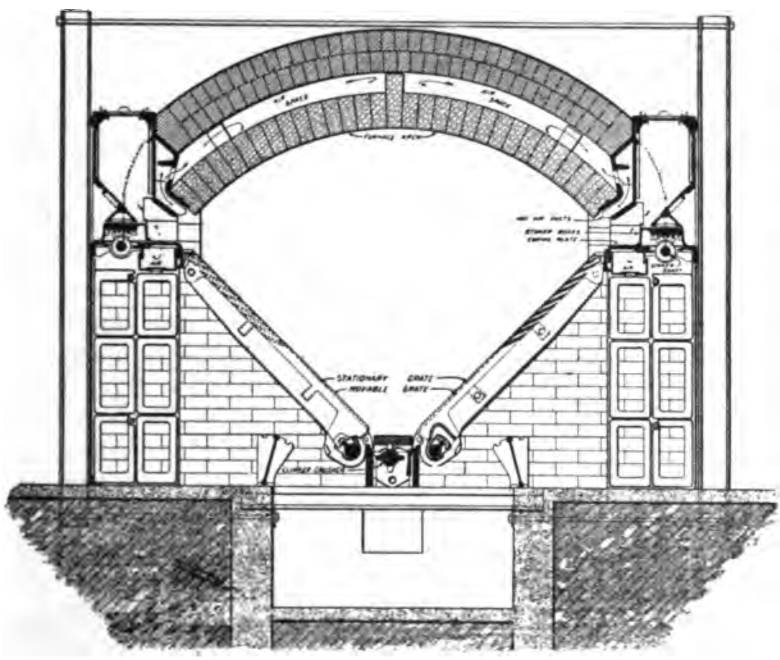

Figure 41—Vertical cross section of side-feed stoker, Murphy model.

tained. Between the sides of the arch and these side plates there are a series of openings, through which air is admitted over the fire after it has passed over the outside of the main arch and been heated. An auxiliary arch is usually sprung over the main arch, and an air space is left between the two. The coking plate is cooled by passing air beneath it to the back of the furnace from whence it passes to the air space between the arches and is there admitted over the fire.

Coal is fed from the magazine, as illustrated in Figure 41, by stoker boxes which move back and forth on the coking plate and push the coal through the throat opening and discharge it on the grates. The stoker boxes move back and forth a fixed amount and are operated by a small segmental gear keyed to the stoker shaft, and this is, in turn, driven by the engine or motor provided for this purpose, and also to impart motion to the grates. The amount of coal fed to the furnace in this type is controlled entirely by the speed of the driving engine or motor.

The coal when pushed into the furnace is ignited by the heat of the arch. The volatile products are distilled off in the presence of the heated air supply through the ducts at the side of the arch. The ignited fuel is pushed by these stoker boxes and the fresh fuel entering the furnace onto the grate bars, where it is completely coked and carried through the various stages of combustion, finally to be dumped out at the bottom in the form of ash and clinker. The grate bars in this type of stoker slope from the sides toward the center, where a device is placed for grinding up the clinker and dumping it into the ash pit. The grate bars extend from the coking plate to the clinker breaker, alternate bars being movable at their lower ends both above and below the surface of the stationary bars, the upper ends being pivoted at the coking plate. The clinker bars in the two types of breakers differ radically. In one of the types of clinker breaker, a hollow iron bar with projections on its surface and running the entire length of the furnace is used. This bar is rotated and grinds up the clinker. A second type of clinker breaker has heavy iron disks with projections on their surface placed at the bottom of the V formed by the grate bars and actuated by a reciprocating bar connected to the driving engine.

With this type of stoker a large amount of coking space per square foot of grate surface is always provided, and they are usually set with ample combustion space. The main difficulty that has been encountered is in keeping the grates evenly covered. This has been overcome, however, to some extent by changing the stroke of the

stoker boxes so that the fuel will be fed to the furnace in such a manner that an even fire will be maintained. The device for the handling of the clinker does not take care of the clinker at all times. It is especially true that the clinker must be removed through the firing door, by hand with a hook, when the fires are forced hard. This operation usually results in the production of smoke,

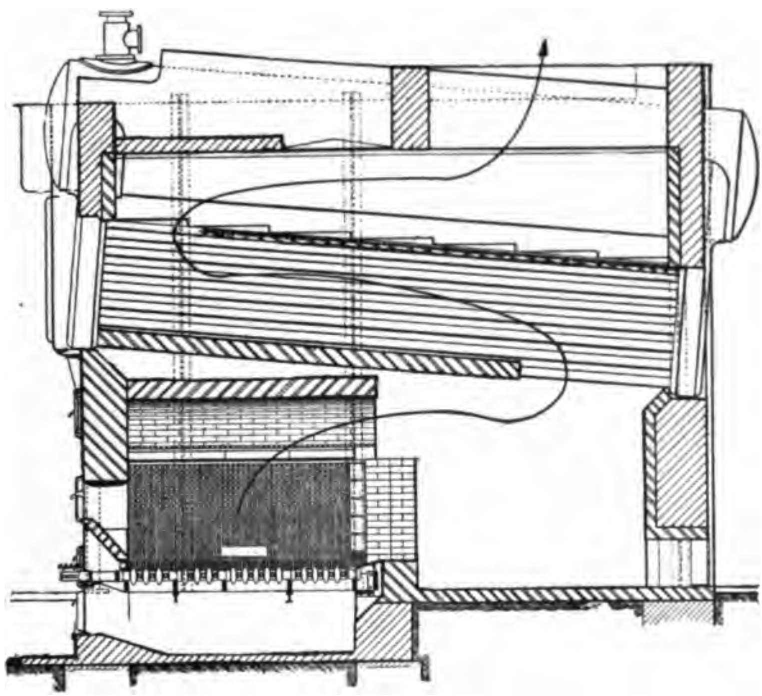

Figure 42—Side-feed stoker, Murphy model, as applied to Heine water-tube boiler, flush-front setting.

as the fires are usually burned short to allow the clinker to rot so it can be removed. When the clinker is removed, large quantities of green fuel are fed to the furnace by hand manipulation of the stoker boxes, and the fire is liberally hooked until it is in good condition. This operation usually results in producing smoke. Due to the ease of access to the fire, this type of stoker is subject to considerable abuse in firing by hooking the fire through the

front door. This tends to cause a very intense fire, and, if the grates are kept well covered, will not cause excessive smoke, due mainly to the provision of ample refractory surfaces and liberal over-fire air supply. When allowed to operate with short overhanging fires which are well burned out at the bottom of the grate, the use of the hook to stir up the fire is usually productive of much smoke. These stokers are usually set with the Dutch oven or a modification thereof. The usual Dutch oven setting

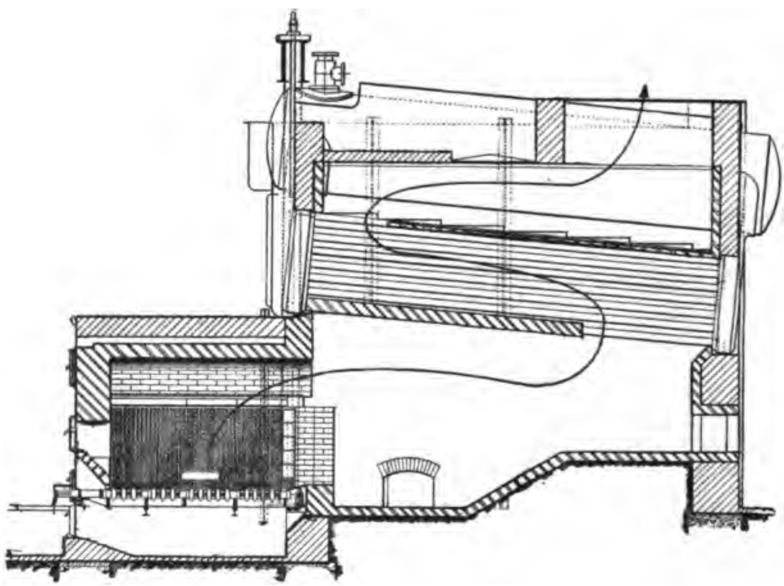

Figure 43—Side-feed stoker, Murphy model, as applied to Heine water-tube boilers, extended oven setting.

is known as the extended-front, and the modification thereof as the flush-front setting.

Figure 42 illustrates a stoker of this type, Murphy Model, as applied to a Heine water tube boiler with flush front setting. This setting should only be used where space available is very much restricted, in that it has the disadvantage that all the coal fired usually is charged to the magazine by hand. This usually results in the back portion of the grate being uncovered due to a lack of coal at this part of the magazine. Furthermore, it has the dis-

advantage of exposing a part of the heating surface of the boiler, only to heat radiated from the arch.

Figure 43 represents an extended-front setting of a Murphy Stoker as applied to a Heine water tube boiler. This setting has the advantages of the fire tile roof in the combustion chamber.

Figure 44 shows an extended front setting of a Murphy Stoker as applied to a B. & W. water tube boiler.

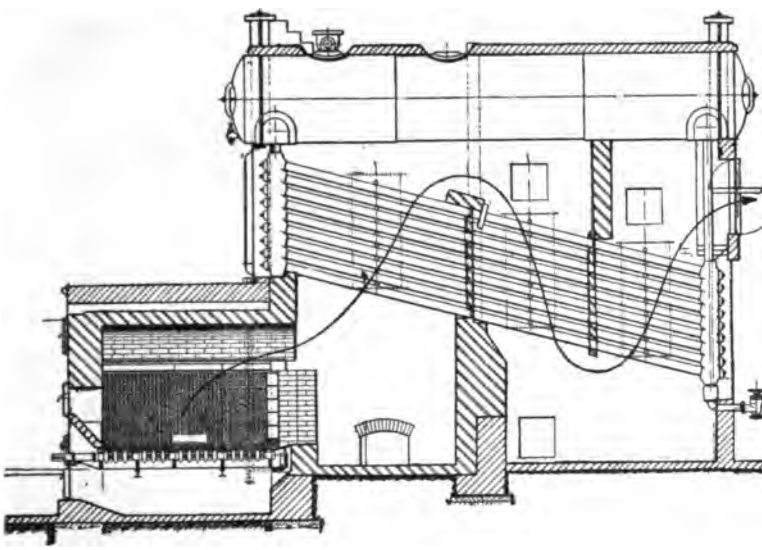

Figure 44—Side-feed stoker, Murphy model, as applied to Babcock & Wilcox water-tube boiler, extended oven setting.

The distance from the grates to the exposed tube surface is somewhat restricted in this setting, and should be remedied by setting the boiler higher.

Figure 45 illustrates an extended front setting of a Murphy Stoker as applied to a return tubular boiler.

Figure 46 shows an extended front setting of a Murphy Stoker as applied to a Stirling water tube boiler.

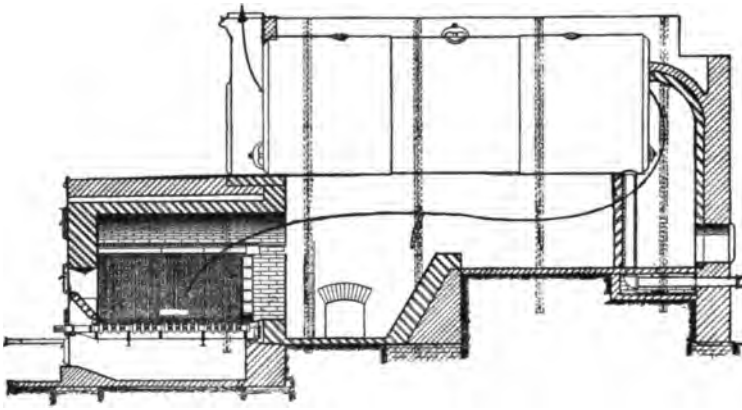

Figure 45—Side-feed stoker, Murphy model, as applied to horizontal return tumular boiler, extended front setting.

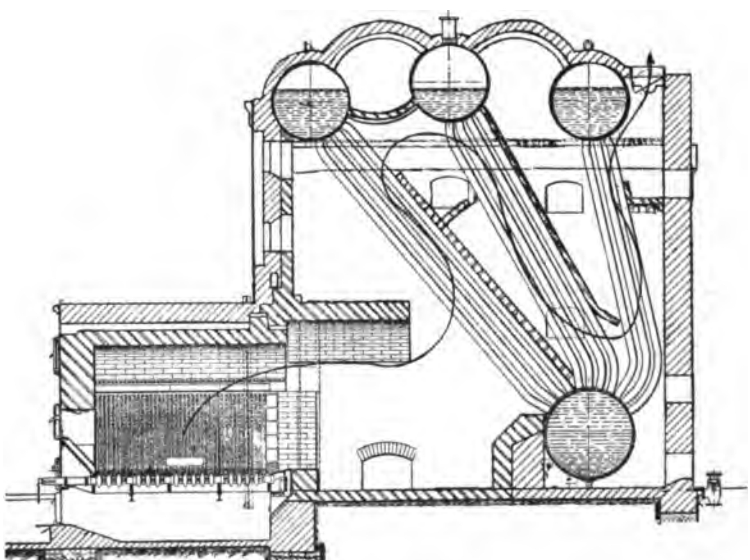

Figure 46—Side-feed stoker, Murphy model, as applied to Stirling water-tube boiler.

TABLE 7—*Detail of data taken on plants equipped with side-feed stokers.*

No. of Instal-lation	Coal			Stoker			Furnace.										
									Dimensions Feet and inches.								
	Commercial Name	Size	Quantity per yr. Tons	Kind of Stoker	Thickness of Fire Inches	Frequency of Cleaning	No.	Grate Area Sq. Ft.	Grate to H. S.		Width	Length	Front Furnace to Front Boiler	Height Coking arch		Length Coking Arch	Height Arch Rear Furnace
									Aver.	Min.				Front	Back		
1	Pittsburgh	Slack	13,000	Murphy	4-5	2 in 24 hrs.	3	50.0	9'-0"	5'-6"	5'-10"	6'-8"	8'-0"	6"-4'-0"	6"-4'-0"	8'-8"	4'-4"
2	do	do	6,000	do	4-6	Continuously	4	36.0	6'-0"	3'-0"	4'-6"	6'-0"	6'-0"	6"-3'-0"	6"-3'-0"	8'-0"	3'-0"
3	do	do	10,000	do	5	do	6	60.0	....	....	6'-0"	7'-0"	7'-9" 8'-0"	6"-4'-3"	6"-4'-3"	9'-0"	....
4	do	do	7,700	do	6	do	3	80.5	10'-0"	6'-0"	7'-3"	7'-10"	13'-0"	12"-6'-0"	12"-6'-0"	7'-0"	....
5	do	do	15,000	do	6	do	5	115.0	9'-0"	7'-6"	10'-0"	8'-0"	....	12"-6'-6"	12"-6'-6"	9'-0"	....
6	do	Nut & Slack	1,250	do	2½-12	do	2	55.0	9'-0"	6'-0"	5'-9"	6'-8"	9'-0"	6"-2'-8"	6"-2'-8"	7'-6"	....
7	do	Slack	3,100	do	4-5	8 in 24 hrs	4	40.0	10'-0"	6'-0"	5'-0"	6'-0"	7'-7"	6"-3'-10"	6"-8'-10"	6'-0"	....
8	do	Run of Mine	775	do	3-4	2 " 24 "	2	30.0	6'-7"	....	4'-0"	6'-4"	7'-4"	6"-2'-6"	6'-2"-6"	7'-6"	....
9	do	Slack	11,000	do	5-7	2 " 24 "	5	41.0	....	5'-0"	4'-8"	8'-0"	0	6"-4'-0"	6"-4'-0"	8'-0"	....
10	do	do	9,000	do	6	2 " 24 "	2	60.0	6'-0"	3'-0"	7'-0"	6'-0"	7'-0"	6'-3"-6"	6"-3'-6"	6'-0"	....
11	Youghiog-heny	Nut	1,320	do	6	Continuously	1	33.0	....	....	6'-0"	5'-6"	2'-9"	....	....	5'-6"	....
12	Pittsburgh	2" Nut & Slack	130,000	do	4-8	Varies	40	96.5	9'-6"	2'-0"	6'-0"	7'-0"	7'-0"	6"-4'-0"	6"-4'-0"	7'-0"	....
13 (a)	do	¾" do	18,250	do	4-8	2 in 24 hrs	8	60.0	8'-0"	4'-0"	5'-0"	7'-0"	7'-11"	6"-3'-6"	6"-3'-6"	7'-0"	....
(b)	do	do	18,250	do	4-8	2 " 24 "	8	60.0	10'-0"	5'-0"	5'-0"	7'-0"	7'-11"	6"-3'-6"	6"-3'-6"	7'-0"	....
14 (a)	do	2" do	....	do	5-7	3 " 24 "	4	95.7	18'-0"	15'-0"	5'-6"	7'-0"	8'-10"	6"-4'-0"	6"-4'-0"	7'-0"	....
(b)	do	do	....	do	5-7	3 " 24 "	4	80.5	16'-0"	14'-0"	5'-2"	7'-0"	....	6"-4'-0"	6"-4'-0"	7'-0"	....
(c)	do	do	....	do	5-7	3 " 24 "	8	78.2	8'-0"	5'-0"	5'-0"	7'-0"	7'-11"	6"-4'-0"	6"-4'-0"	7'-0"	....
(d)	do	do	....	do	5-7	3 " 24 "	6	73.5	....	....	....	....	....	....	....	....	....
(e)	do	do	....	do	5-7	3 " 24 "	2	73.5	....	....	....	....	....	....	....	....	....

TABLE 7—*Detail of data taken on plants equipped with side-feed stokers*—Continued.

No. of Instal-lation	Boilers: Type	Boilers: Builders Rated H. P.	Boilers: No. Instal-led.	Boilers: No. used to carry: Aver. Heavy Load	Boilers: No. used to carry: Aver. Light Load	Boilers: Steam Pressure Lbs. per sq. in.	Load: Requirement	Load: Nature	Load: Character
1	B. & W. Water Tube	750	3	3	3	125	Power	Uniform	Factory
2	Horizontal Return Tube	600	4	4	....	90	do	do	do
3	B. & W Water Tube	1,500	6	4	....	90-100	do	Variable	do
4	1 Wickes do 2 Stirling do	1,100	3	2	2	110	do	Uniform	do
5	B. & W. do	2,500	5	3	....	150	do	Variable	Mill
6	B. & W. do	500	2	1	1	115	Power & heat	do	Bldg.
7	Heine do	668	4	3	2	125-130	do	do	do
8	Horizontal Return Tube	200	2	1	....	100	do	do	Factory
9	do	750	5	5	....	100	Power & refrigeration	Uniform	do
10	Wickes Water Tube	800	2	2	....	140	Power	Variable	Shop
11	Erie City Fire Tube	150	1	1	....	100	Power & heat	do	Factory
12	B. & W. Water Tube	10,000	20	15-20	6-10	165	Power	do	Power
13 (a)	B. & W. do	1,600	4	3	1	150	do	do	do
(b)	Stirling do	1,600	4	3	1	150	do	do	do
14 (a)	Heine do	750	2	2	1	145	do	do	do
(b)	Heine do	650	2	2	1	145	do	do	do
(c)	B. & W. do	1,600	4	4	2	145	do	do	do
(d)	Standard do	900	3	3	2	145	do	do	do
(e)	Atlas do	250	2	2	0	145	do	do	do

TABLE 7—*Detail of data taken on plants equipped with side-feed stokers*—Continued.

No. of Installation	Rating: Average Load. Heavy: Hrs. per day	Heavy: Coal per day (tons)	Light: Hrs. per day	Light: Coal per day (tons)	Draft: Kind	Inches of Water: Furnace	Rear of Boiler	Breech-ing	Base of Stack	Conditions Under Which taken	Breeching: Distance Stack to nearest boiler Feet.	Size Feet	Where meas-ured.	No. of Ells.
1	24				Natural	0.17			0.20	Just starting Plant	5'-0"	6'-0"x3'-0"	At middle boiler	1
						0.05								
2	24	30.0			do	0.10					10'-0"	5'-0"x5'-0"	At stack	1
3	24	35.0			do						6'-0"	4'-0"x4'-0"	do	1
						0.13					For Wicks			
4	24	38.4			do	0.15					6'-0"			0
						0.40								
5	24	50.0			do	0.50								1
6	10				do	0.24		0.60			20'-0"	4'-8"	Near Stack	2-45°
7	8	12.0	16.0		do	0.22					20'-0"	5'-0"	do	2-60°
8	10	2.6			do	0.10				Light fire	12'-0"	2'-0"x2'-0"	At Stack	2
						0.15								
9	24	30.0-35.0			do	0.20				Normal	15'-0"	5'-0"	do	2
						0.15								
10	10	30.0			do	0.20				do	8'-0"			1
11	11	4.2			do	0.13								
												4'-0"x6'-6"	Boiler	
12	7		19		do	0.23	0.45			Normal	4'-0"	3'-6"x5'-6"	Stack	1
13 (a)	7		19		do	0.10		0.35		do		Stack on	boiler	0
								0.20						
(b)	7		19		do	0.09		0.45		do		do	do	0
14 (a)	16		8		do					do		do	do	0
(b)	16		8		do					do		do	do	0
(c)	16		8		do					do		do	do	0
(d)	16		8		do					do		do	do	0
						0.05								
(e)	16				do	0.10			0.25	do		do	do	0

TABLE 7—*Detail of data taken on plants equipped with side-feed stokers*—Continued.

No. of Instal-lation	Dampers		Stack				Smoke Records					
	Kind	Usual position	No.	Height Feet	Size Feet	Area Square Feet	Total mins. of obser-vation	Mins. in one hr. of			Aver. per cent of Black Smoke	Load during obser-vations.
								100 to 80 %	80 to 60 %	Stack Clean		
1	Hand......	½ open............	1	110'-0"	5'-0"	19.6	60	0.00	0.00	34.50	8.8	Normal
2	do	⅔ open............	1	60'-0"	5'-0"	19.6	60	0.00	0.00	45.00	4.0	do
								0.00	0.00	53.75	1.0	
3	do	½ open............	2	125'-0"	7'-0"	38.5	60	3.75	3.50	10.75	29.0	do
				115'-0"	4'-0"	12.6		0.00	0.50	52.25	5.0	
4	do	Wide open.........	3	100'-0"	4'-6"	15.9	60	0.50	0.50	43.50	5.0	do
					11'-6" Top	103.9						
5	do	½ open............	1	250'-0"	15'-6" bottom	188.7	60	0.75	1.50	45.00	7.8	do
6	do	Nearly closed......	1	183'-0"	4'-8"	17.1	60	0.00	0.00	60.00	0.0	Light
7	Automatic	....	1	220'-0"	5'-0"	19.6	60	0.00	0.50	56.00	2.4	....
8	Hand......	Wide open.........	1	98'-0"	3 x 3	9.0	60	0.00	0.25	49.00	4.7	Normal
					5'-0" Top	19.6						
9	do	do	1	100'-0"	8'-0" bottom	50.3	60	6.25	2.75	47.00	14.0	do
10	do	½ open............	1	140'-0"	6'-0"	28.3	60	2.50	5.75	33.25	16.5	do
11	....	....	1	60'-0"	2'-0"	3.1	60	6.00	3.00	41.25	16.6	do
12	Hand.....	Varied............	10	120'-0"	7'-0"	38.5	60	0.00	0.00	15.00	17.7	do
				1-140'-0"								
13 (a)	do	Wide open.........	2	1-115'-0"	6'-6"	33.2	60	1.75	0.50	53.50	4.4	....
(b)	do	do	4	115'-0"	4'-6"	15.9	60	0.00	0.00	36.25	4.6	....
					6'-0" for 15-0							
14 (a)	do	do	2	145'-0"	3'-6" " 105-	9.6	60	0.00	0.25	52.50	2.5	....
(b)	do	do	2	125'-0"	4'-6"	15.9	60	0.00	0.00	46.00	5.0	....
(c)	do	do	2	145'-0"	6'-6"	33.2	60	0.00	0.00	41.00	6.5	....
(d)	do	do	3	105'-0"	3'-0"	7.1	60	0.00	0.00	47.75	4.0	....
(e)	do	do	1	115'-0"	3'-0"	7.1	60	0.00	0.00	56.75	1.0	....

TABLE 7—*Detail of data taken on plants equipped with side-feed stokers*—Continued.

No. of Instal-lation.	Remarks.
1	Good equipment, general plant conditions good but not much care used in firing.
2	Old equipment but fairly well installed. General plant conditions poor and much care used in operation.
3	Good equipment, fairly well installed. General plant conditions fair but not much care used in operation.
4	Good equipment, properly installed and fairly well operated.
5	Good equipment, properly installed, general plant conditions good but not much care used in firing.
6	Both coal and natural gas used. Good equipment with good plant conditions, well operated.
7	New equipment, well installed and operated.
8	Good installation but only fairly well handled.
9	Old equipment, not properly installed and very poorly operated. General plant conditions poor.
10	Good equipment, fairly well installed but poorly operated.
11	
12	Combustion space somewhat restricted, plant conditions poor. Considerable hooking through front doors during heavy load period.
13 (*a*)	Combustion chamber ample. Fires hooked considerably but grates usually kept pretty well covered.
(*b*)	Large combustion chamber with ample refractory surface. Although fires hooked considerably not much smoke emitted.
14 (*a*)	Combustion chamber ample in all cases. Boilers operate above rating most of time, fired very hard and fires hooked almost continuously. Stacks practically clean at all times except when starting or cleaning fires.
(*b*)	
(*c*)	
(*d*)	
(*e*)	

Results of Survey of Side-feed Stoker Plants.

Examinations were made of nineteen plants in which the side-feed type of stoker was installed. Pittsburgh coal was used in eighteen of these plants and Youghiogheny coal in one plant. Slack or nut and slack size fuel was used in eighteen plants and run of mine in one plant. These plants varied in size from 150 to 10,000 boiler horse power, and contained from 1 to 20 boilers per plant. The thickness of the fire varied from 2½ to 12 inches, and natural draft was used in all plants. The draft in the furnace at thirteen plants varied from 0.05 to 0.50 inches of water; at the rear of the boiler; in four plants from 0.20 to 0.60 inches of water; and in the stack at two plants from 0.20 to 0.60 inches of water. Steady loads were carried by four plants, and variable loads by ten plants.

Observations made upon twenty-one stacks of boilers equipped with these stokers, show the following average conditions ase regards smoke production: 1.9 minutes per hour of smoke equal to or greater than 60 per cent. black, 43.80 minutes per hour when no smoke issued from stack and an average percentage of 7.6 black smoke from observations. Observations on this same class show a maximum of 9.00 minutes per hour and a minimum of 0.00 minutes per hour smoke equal to or greater than 60 per cent. Maximum of 60.00 minutes per hour and a minimum of 10.75 minutes per hour in which no smoke issued from stacks; and a maximum of 29.0 per cent. and a minimum of 1.0 per cent. black smoke from observations.

Underfeed Stokers.

This type of stoker differs radically from any other type so far illustrated, in the manner of feeding and burning the coal and getting rid of the clinker. There are at present two well known types on the market, both employing the same underlying principles in feeding and burning the fuel, but varying considerably in their construc-

tion, general position of fuel bed, and method of getting rid of the clinker.

In the type that first appeared on the market, the retorts are placed horizontally the length of the entire fur-

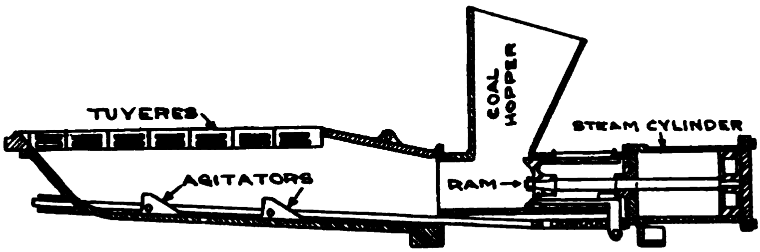

Figure 47—Longitudinal section of underfeed stoker, Jones model.

nace. The number of retorts varies with the size of the furnace, and when only one retort is used, it is placed in the center of the furnace. Coal is fed from a hopper placed at the front of the retort as illustrated by Figure

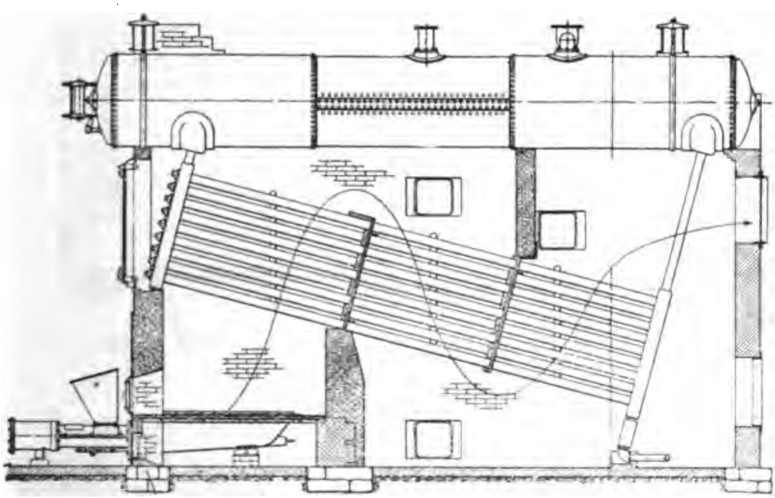

Figure 48—Underfeed stoker, Jones model, as applied to Babcock & Wilcox water-tube boiler.

47 by means of a ram actuated directly from a steam cylinder which is placed in front and beneath the hopper so that the coal feeds by gravity to the ram when the latter is withdrawn from the retort. This cylinder also

actuates an agitator or auxiliary ram which moves the coal from the front to the back of the retort and distributes it uniformly beneath the fuel bed. This agitator also gives the fuel an upward and backward movement, thereby automatically breaking up the fire at each charge. The fuel for combustion moves from the bottom of the retort up into the region where combustion takes place, and as it approaches this region, the volatile gases begin to distill off and pass through the incandescent fuel bed.

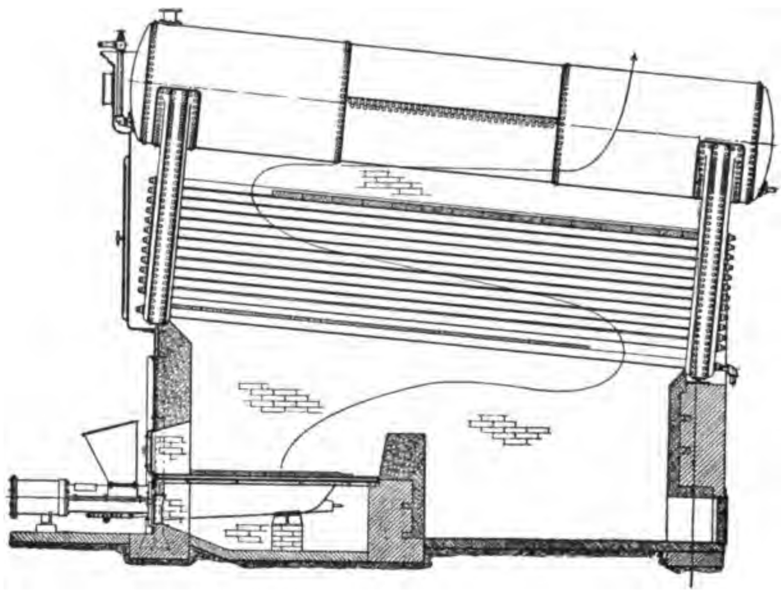

Figure 49—Underfeed stoker, Jones model, as applied to Heine water-tube boiler.

In the presence of the incandescent carbon, the complete combustion of the volatile gases takes place with a short flame. Air, which supports the combustion, is supplied under pressure through tuyere blocks placed along the side and at the top edge of the retort. As the fuel is supplied to the fire, a small portion of it, which has not been completely consumed, and the clinker fall off the top of the fuel bed and roll onto a dead plate at the side of the retort. Here, combustion of the remaining unconsumed

portion of the fuel is completed by the excess air which enters through the tuyeres.

On account of the high temperature encountered in the operation of this type of stoker, most of the ash is fused

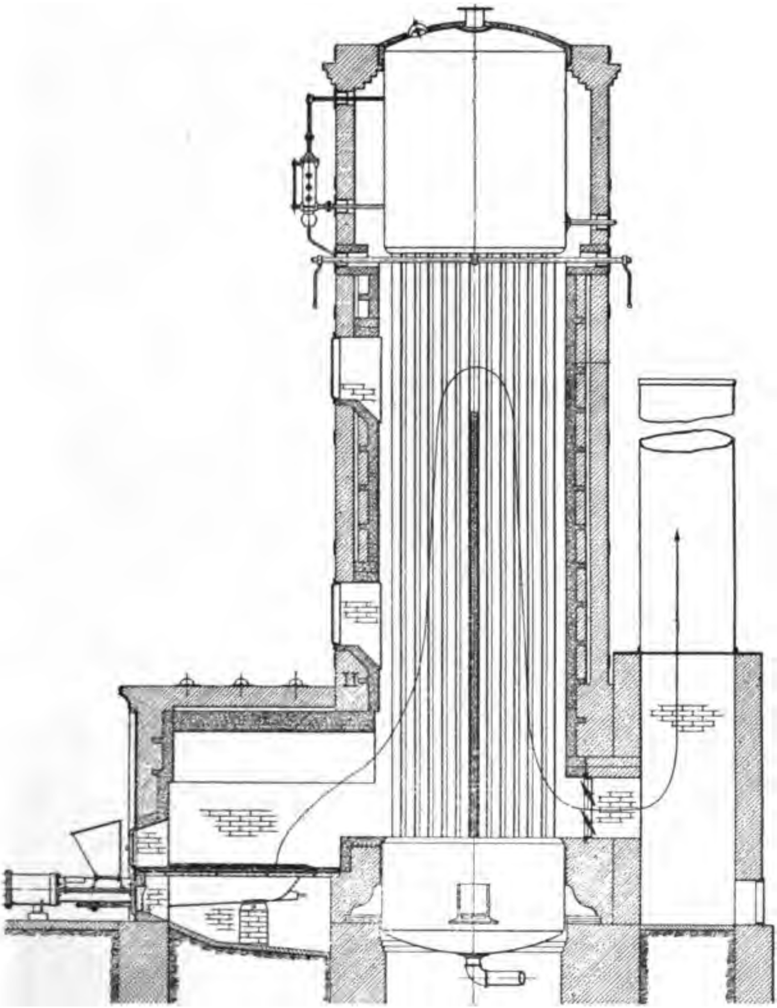

Figure 50—Underfeed stoker, Jones model, as applied to Wickes water-tube boiler.

to clinker, which must be periodically removed through the front door by means of a hook. This operation usually re-

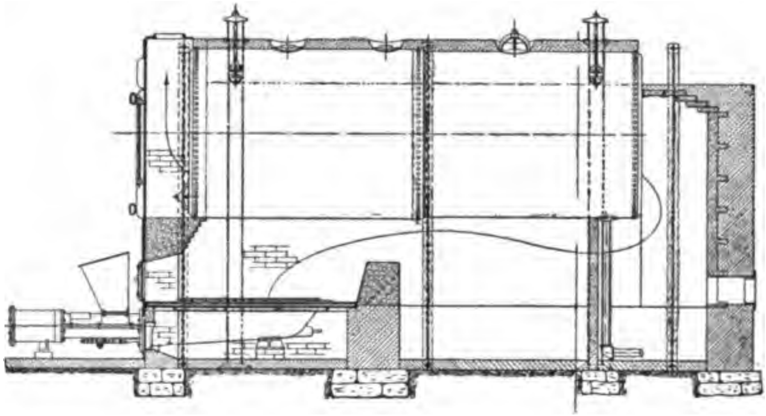

Figure 51—Underfeed stoker, Jones model, as applied to a horizontal return tubular boiler.

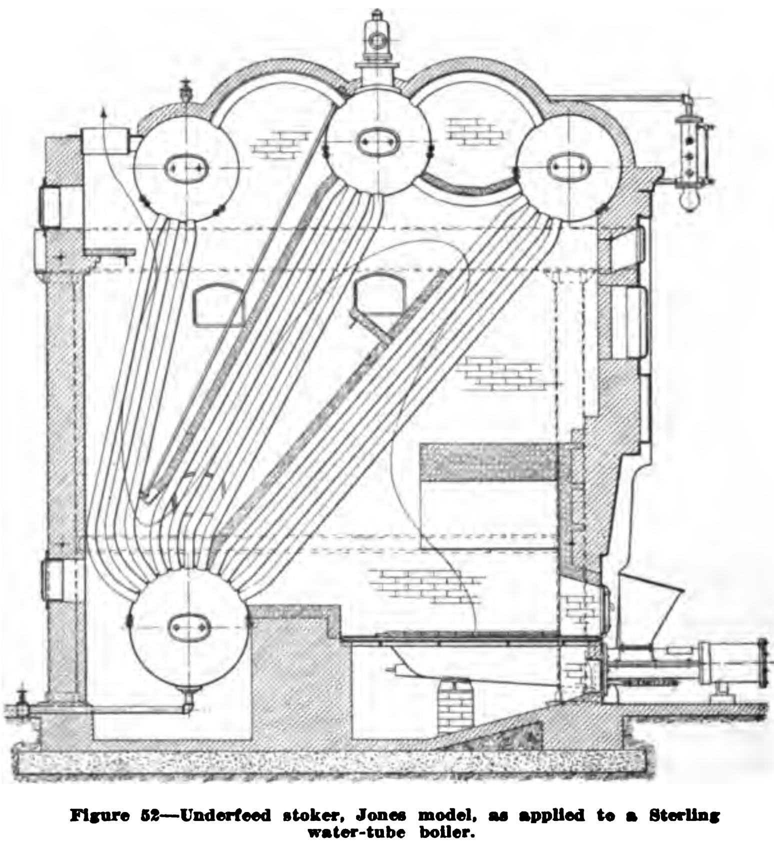

Figure 52—Underfeed stoker, Jones model, as applied to a Sterling water-tube boiler.

sults in the production of smoke, especially if the fire is not allowed to burn down somewhat before cleaning. With this type of stoker the fuel and air supplied are automatically regulated, bearing a definite relation to each other and to the load under which the boiler is operating.

No arch or refractory surfaces to aid in the combustion of the volatile gases is required with this type of stoker, as these gases are intimately mixed and burn with a very short flame, complete combustion taking place within a very short distance from the fuel bed. Ample combustion space should be provided. This allows ample time and space for combustion, when operating at high boiler capacities, and, also aids in giving a better mixture

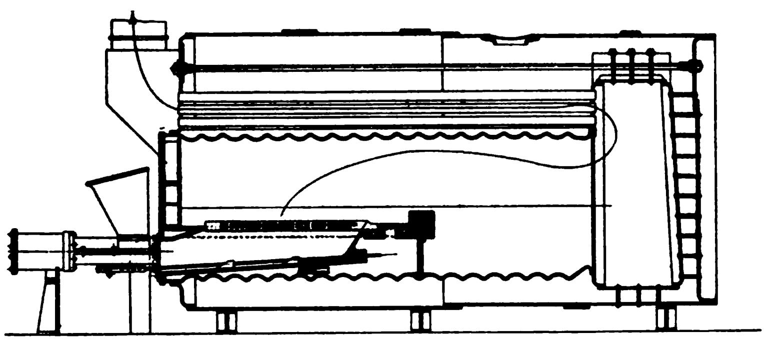

Figure 53—Underfeed stoker, Jones model, as applied to a Scotch marine boiler.

of the products of combustion before they meet the cold surfaces of the boiler. In order to eliminate cleaning of these furnaces by hand, a device for removing the clinker from the furnace has recently been applied to the stoker. A set of movable grate bars has been used to replace the dead plates placed at the sides of the retorts. The clinker falls on these grate bars and is moved, by their action, to the rear of the furnace, where it is dumped periodically from the furnace into the ash pit by means of a ram provided for this purpose. This ram is actuated by a steam cylinder placed along the side of the furnace.

Figure 48 illustrates this type of stoker, Jones Model, as applied to a B. & W. water tube boiler.

Figure 49 illustrates this type of stoker, Jones Model, as applied to a Heine water tube boiler.

Figure 50 illustrates this type of stoker, Jones Model, as applied to a Wickes vertical water tube boiler.

Figure 51 illustrates this type of stoker, Jones Model, as applied to a horizontal return tubular boiler.

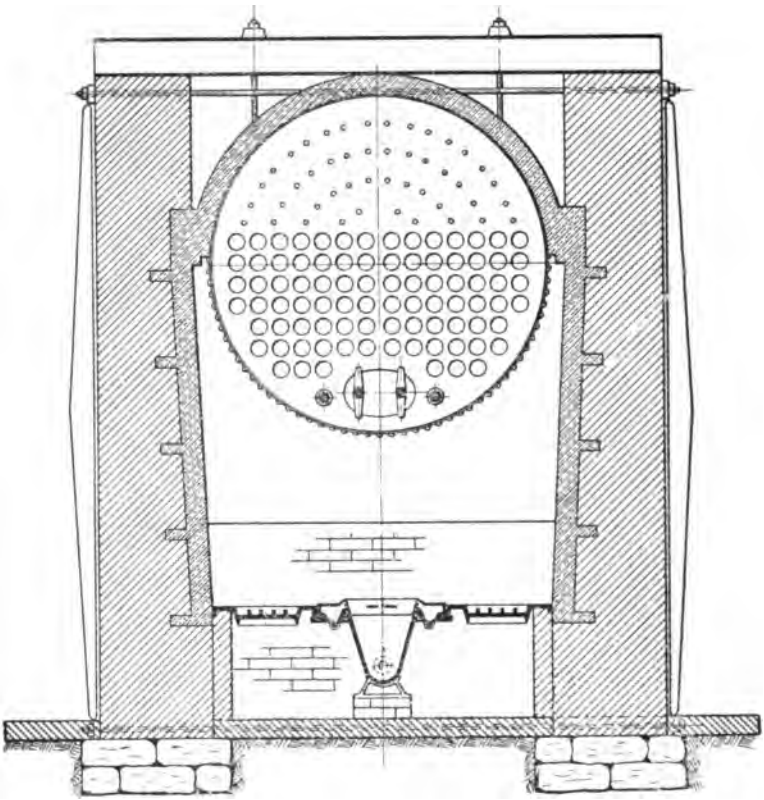

Figure 54—Cross section of underfeed stoker, Jones model, as applied to a horizontal return tubular boiler.

Figure 52 illustrates this type of stoker, Jones Model, as applied to a Stirling water tube boiler.

Figure 53 illustrates this type of stoker, Jones Model, as applied to a Scotch Marine boiler.

Figure 54 illustrates the cross section of this type, Jones Model, as applied to a horizontal return tubular boiler.

The type of underfeed stoker which has met with favor, especially in the larger power stations in the East, has its tuyere blocks for air admission inclined from the front of the furnace toward the bridge wall, and has its

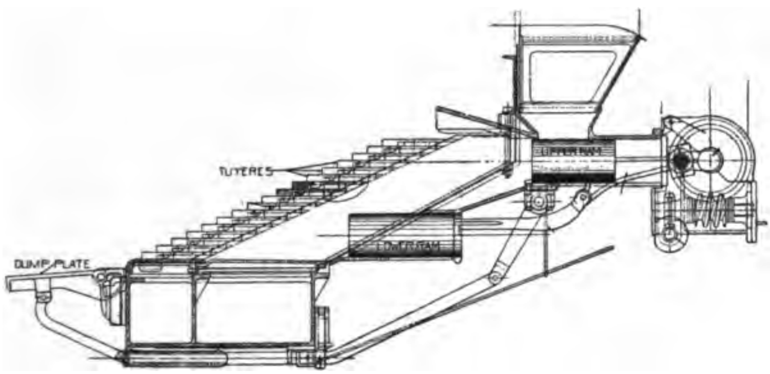

Figure 55—Longitudinal section of underfeed stoker, Taylor model.

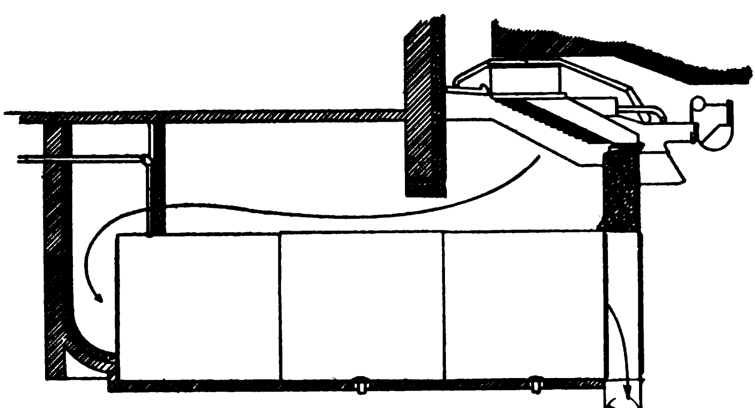

Figure 56—Underfeed stoker, Taylor model, as applied to a horizontal return tubular boiler.

retorts formed between the tuyere blocks and placed across the front of the furnace. The coal is fed to the furnace from a hopper placed across the front of the furnace, as illustrated by Figure 55. It feeds from this hopper by gravity to two rams, one placed a short distance above the other, the lower one being somewhat ahead of the

upper one, both of them, however, operating in one of the retorts between the tuyeres. The upper ram receives its fuel from the hopper and forces it into the top of the retort. The lower ram receives its charge only as the coal

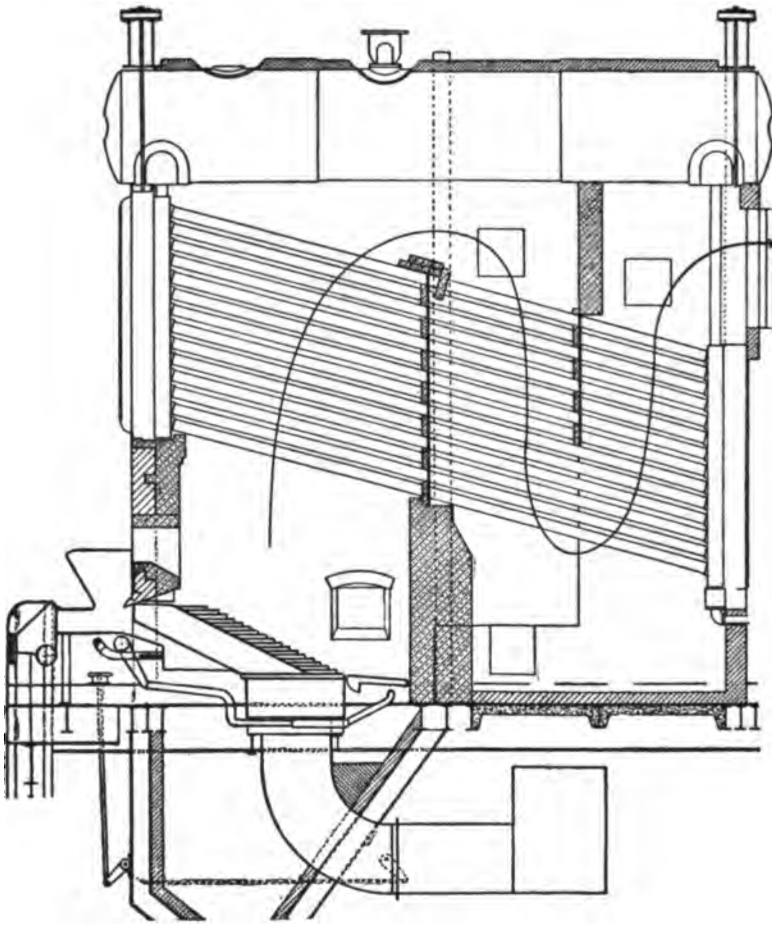

Figure 57—Underfeed stoker, Taylor model, as applied to a Babcock & Wilcox water-tube boiler.

descends from the upper ram, and its stroke should be so regulated that an even fuel bed will be maintained. The inclined furnace allows all refuse to be deposited at the rear of the furnace, and the fuel to be worked downward

and toward the back, in its process of combustion. The ash which is fused to clinker is deposited on a dead plate at the rear of the stoker and is periodically dumped into the ash pit. Forced draft and automatic regulation of the coal and air supply are also employed with this stoker. The rams for pushing the coal into the furnace are driven by means of crank arms placed at the front of the stoker and which are in turn driven through gears by an engine or a motor. The fan for supplying the air is usually connected to this same driving mechanism, especially in

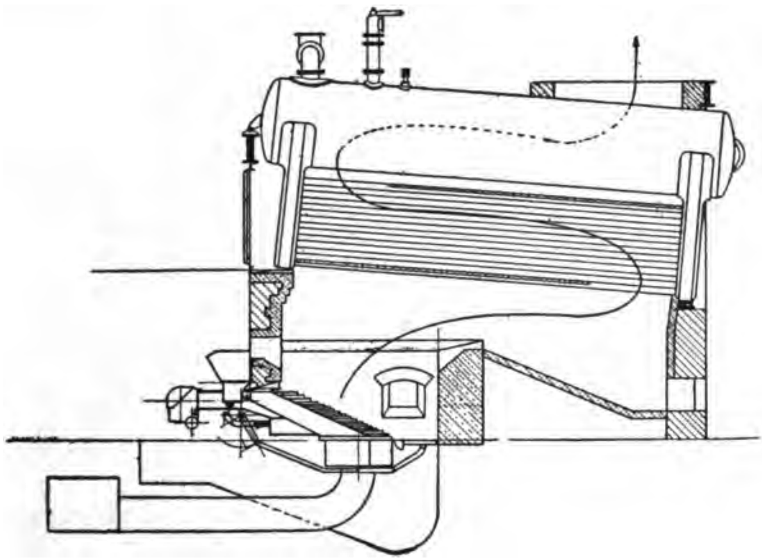

Figure 58—Underfeed stoker, Taylor model, as applied to Heine water-tube boiler.

smaller installations. This stoker has the advantage over the hand cleaned type, that provision has been made for cleaning the fire instead of being compelled to rake the clinker out by hand. The inclining of the tuyeres and provision for cleaning the fire also permit of the installation of a larger number of smaller retorts, which distribute the heat more uniformly across the entire width of the boiler. Ample space should be provided for the clinker and refuse to gather in, so that it can be dumped from the furnace without breaking up the fire. This will also aid

materially in decreasing the length of time required to burn down the fire, preparatory to cleaning.

A stoker of this type, Taylor Model, is shown by Figure 56, applied to horizontal return tubular boiler.

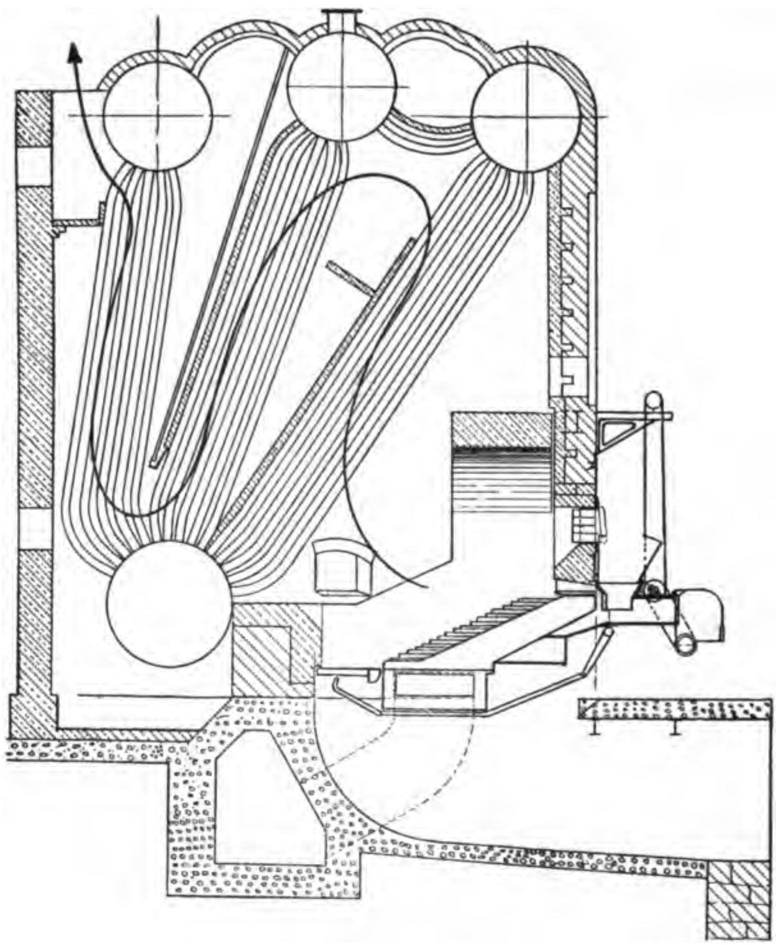

Figure 59—Underfeed stoker, Taylor model, as applied to a Sterling boiler.

Figure 57 shows this type of stoker, Taylor Model, applied to a B. & W. water tube boiler.

Figure 58 shows this type of stoker, Taylor Model, applied to a Heine water tube boiler.

Figure 59 illustrates this type of stoker, Taylor Model, as applied to a Stirling water tube boiler.

Figure 60 illustrates this type of stoker, Taylor Model, as applied to a Rust water tube boiler.

The underfeed stoker has the advantage of positive draft, and hence its operation is independent of weather

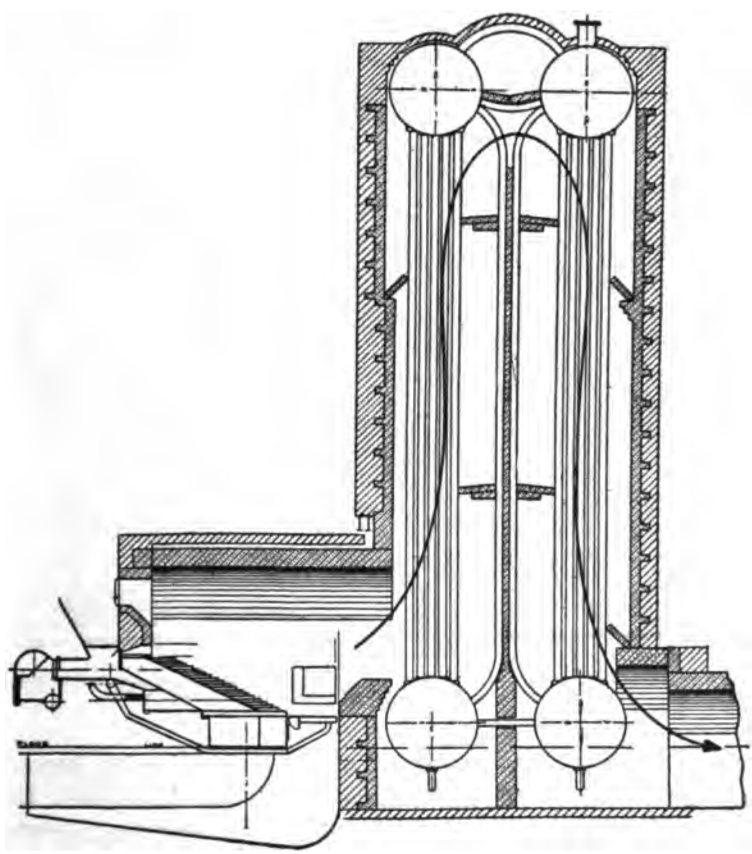

Figure 60—Underfeed stoker, Taylor model, as applied to Rust water-tube boiler.

conditions. It meets changes of load quickly, and on test has shown that boilers can be brought from a standstill to a high rating in a very short time. This stoker affords a means for increasing both economy and capacity of plants, which, by gradual growth, have added so many

boilers to a stack that the capacity of the stack has been exceeded. In other words, with the additional boilers, the natural draft of the stack is no longer of sufficient intensity to supply the necessary air to burn the amount of coal required in order to develop high boiler ratings. A much shorter stack will suffice with the underfeed stoker than is required where natural draft is used. It is only necessary to have enough draft to carry the gases of combustion through the boiler and out of the stack,

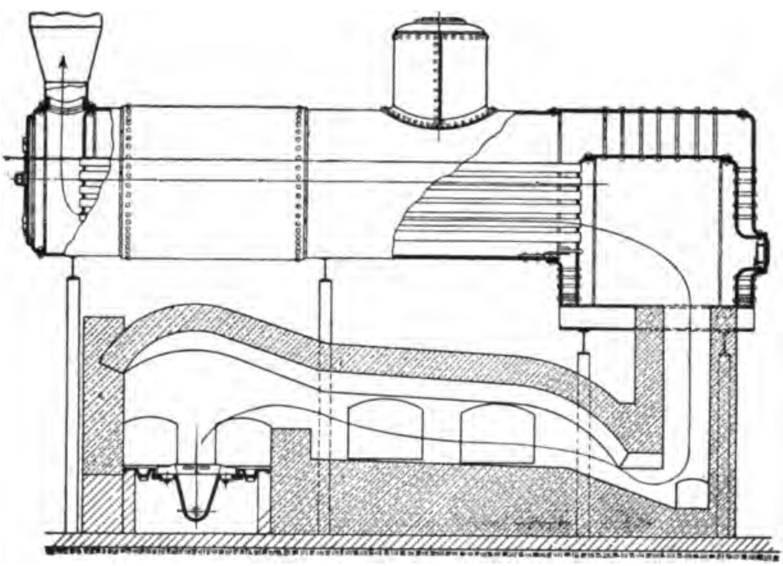

Figure 61—Underfeed stoker, Jones model, as applied to a furnace for heating forgings. This furnace is equipped with a waste-heat boiler.

all the air that is required to burn the coal being forced through the fire. These stokers have sometimes been installed under conditions not favorable to their best operation. Under these conditions they have developed powers in excess of boiler rating, and they conform to very stringent smoke laws when using a good grade of low volatile bituminous coal.

Attention has been called previously to the application of the mechanical stoker to the metallurgical furnace. The following cuts represent such installations that are in

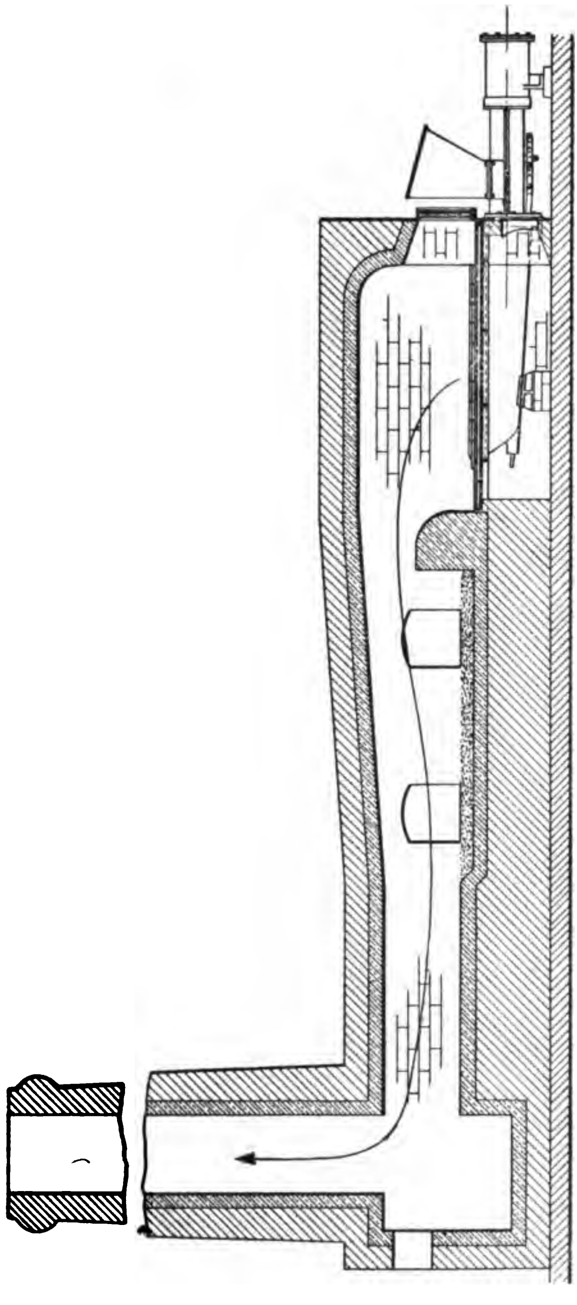

Figure 68—Underfeed stoker, Jones model, as applied to a billet heating furnace at the plant of the Oil Well Supply Co., Pittsburgh, Pa.

very successful operation, having aided in increasing both the quality and quantity of the product.

Figure 61 represents the underfeed stoker, Jones Model, as applied to a furnace for heating forgings. This furnace is equipped with a waste heat boiler.

Figure 62 shows the underfeed stoker, Jones Model, as applied to a billet heating furnace at the plant of the Oil Well Supply Company.

Figure 63 shows the underfeed stoker, Jones Model, in use with a hot air furnace—sectional plan.

TABLE 8—*Detail of data taken on plants equipped with underfeed stokers.*

No. of Instal-lation	Coal			Stoker			Furnace.										
									Dimensions and Feet inches.								
	Commercial Name	Size	Quantity per yr. Tons	Kind of Stoker	Thickness of Fire Inches	Frequency of Cleaning	No.	Grate Area Sq. Ft.	Grate to H. S.		Width	Length	Front Furnace to Front Boiler	Height Coking arch		Length Coking Arch	Height Arch Rear Furnace
									Aver.	Min.				Front	Back		
1	Pittsburgh	Slack	4,500	Taylor	8-12	5 in 24 hrs	3	......	5'-0"	5'-0"	5'-8"	5'-6"	0	......	......	......	......
2	do	Nut & Slack	9,125	Jones	20-30	4-6 " 24 "	2	......	......	......	4'-2"	......	0	......	......	......	......
3	do	Slack	2,708	do	18-30	4-6 " 24 "	1	......	4'-0"	3'-0"	10'-0"	......	0	......	......	......	......
4	do	Nut & Slack	1,600	do	4-16	2 " 12 "	2	......	3'-2"	3'-2"	......	......	0	......	......	......	......
5	N. Y. & Cleve. gas	Run of Mine	7,200	do	12-20	4-6 " 24 "	12	......	......	......	......	......	0	......	......	......	......
6	Pittsburgh	Slack	13,000	do	18	3 " 24 "	6	......	15'-0"	12'-0"	6'-0"	6'-4"	0	5'-0"	4'-5"	......	......
7	do	do	5,350	do	18	3 " 24 "	4	......	2'-0"	1'-6"	......	......	0	......	......	......	......
8	do	do	......	do	12-24	4 " 24 "	4	......	......	......	......	......	0	......	......	......	......
9	do	do	1,035	do	12-15	2 " 24 "	1	......	......	3'-6"	5'-0"	......	0	......	......	......	......
10	do	do	3,700	do	12-15	3 " 24 "	4	......	3'-4"	2'-11"	......	......	0	......	......	......	......

TABLE 8—*Detail of data taken on plants equipped with underfeed stokers*—Continued.

No. of Instal-lation	Boilers						Load		
	Type	Builders Rated H. P.	No. Instal-led.	No. used to carry		Steam Pressure Lbs. per sq. in.	Requirement	Nature	Character
				Aver. Heavy Load	Aver. Light Load				
1	B. & W. Water Tube	690	3	2	2	125	Power & Heat	Variable	Mfg.
2	Scotch Marine	740	2	2	2	100-110	do	Variable	do
3	B. & W. Water Tube	300	1	1	1	115	Power	Uniform	do
4	Horizontal Return Tube	130	2	2		100	Power & heat	do	do
5	do	480	12	12		90-100	Power	Variable	Mill
6	Wilkins & O. W. S. Co. Water	1,200	6	5		120	do	do	Mfg.
7	Gill & Heine do	720	4	3		120	Power & heat	Uniform	Bldg.
8	Macnoll do	500	4	3		100	do	Variable	do
9	Horizontal Return Tube	85	1	1		90-100	do	Uniform	Laundry
10	do	240	4	4		95	Power	Variable	Mfg.

TABLE 8—*Detail of data taken on plants equipped with underfeed stokers*—Continued.

No. of Installation	Rating: Average Load. Heavy: Hrs. per day	Rating: Average Load. Heavy: Coal per day (tons)	Rating: Average Load. Light: Hrs. per day	Rating: Average Load. Light: Coal per day (tons)	Draft: Kind	Draft: Inches of Water. Furnace	Draft: Inches of Water. Rear of Boiler	Draft: Inches of Water. Breeching	Draft: Inches of Water. Base of Stack	Draft: Conditions Under Which taken	Breeching: Distance Stack to nearest boiler Feet.	Breeching: Size Feet	Breeching: Where measured.	Breeching: No. of Ells.
1	18	25.0			Forced					1.5-3.0 in duct	9'-0"	4'-0"x4'-0"		2
2	24	25.0			do	0.25						Stacks on boilers		0
3	12	6.0	12	3.0	do	0.42	0.48		0.48			do	do	0
4	12	4.5			do	0.08					8'-0"			2
5	10	16.0	14	8.0	do						5'-0"	Stacks on 2 boilers		0
6	10	27.0	14	18.0	do							Stacks on boilers		0
7	12	10.0	12	8.0	do						40'-0"			1
8	24				do									
9	10	3.5			do	0.08 0.10					10'-0"	2'-0"x2'-0"	Near Stack	1
10	24				do							Stacks on boilers		0

TABLE 8—*Detail of data taken on plants equipped with underfeed stokers*—Continued.

No. of Instal-lation	Dampers		Stack				Smoke Records					
	Kind	Usual position	No.	Height Feet	Size Feet	Area Square Feet	Total mins. of obser-vation	Mins. in one hr. of			Aver. per cent of Black Smoke	Load during obser-vations.
								100 to 80 %	80 to 60 %	Stack Clean		
1	Hand......	½ open...........	1	125′-0″	6′-0″	28.3	60	0.00	0.00	35.25	9.0	Normal
								0.00	0.00	59.75	0.1	
2	do	¾ open...........	2	100′-0″	5′-0″	19.6	60	0.00	0.00	59.25	0.3	....
3	do	Wide open.........	1	100′-0″	3′-0″	7.1	60	0.00	1.50	10.75	16.0	....
4	do	do	1	60′-0″	3′-0″	7.1	60	0.25	0.50	51.00	2.0	....
								0.00	0.00	36.75	14.7	
5	None......	....	6	....	....	....	60	12.00	1.00	41.50	8.3	Normal
6	do	....	6	110′-0″	3′-6″	9.6	60	0.00	0.00	60.00	0.0	....
7	do	....	1	240′-0″	6′-0″	28.3	60	0.00	0.00	11.25	16.9	Normal
8	Hand......	....	1	....	....	....	60	0.00	0.00	53.50	2.2	....
9	do	Nearly closed......	1	50′-0″	....	....	60	0.00	1.00	52.50	3.0	....
10	None......	....	4	....	3′-0″	7.1	60	0.00	0.00	45.75	5.0	....

TABLE 8—*Detail of data taken on plants equipped with underfeed stokers*—Continued.

No. of Installation.	Remarks.
1	Good equipment, properly installed and well operated. General plant conditions good.
2	Fair equipment, well operated, general plant conditions good.
3	Good equipment in good condition and well operated. General plant conditions good.
4	Old equipment, in poor condition, general plant conditions poor and not much care used in operation.
5	Very old equipment, in poor condition, fairly well installed but poorly operated.
6	Fair equipment, fairly well installed and operated. General plant conditions fair.
7	Good equipment, poorly installed due to cramped quarters. General plant conditions fair.
8	Fair equipment, fairly well installed and operated. General plant conditions very poor.
9	Equipment fairly well installed and operated, general plant conditions fair.
10	Fair equipment, fairly well installed and operated. General Plant conditions good.

RESULTS OF SURVEY OF UNDERFEED STOKER PLANTS.

Examinations were made of ten plants in which the underfeed stoker is installed. Of these plants, nine used Pittsburgh coal and one used New York & Cleveland gas coal. Slack or nut and slack size fuel was used in nine plants and run of mine in one plant. These plants varied in size from 85 to 1,200 boiler horse power and contained from 1 to 12 boilers per plant. The thickness of fire varied from 4 to 30 inches. However, in a majority of plants the fire was carried from 12 to 20 inches thick. The draft in the duct, in the only plant for which data could be obtained, varied from 1.50 to 3.00 inches of water. In the furnaces at four plants, the draft varied from 0.08 to 0.42 inches of water. Steady loads were carried in four plants and variable loads were carried by six plants. As is usual, in the construction of this stoker, no refractory surface was provided over the fire, except in one plant.

Observations made upon twelve stacks of boilers equipped with these stokers show the following average conditions as regards smoke production. 1.35 minutes per hour of smoke equal to or greater than 60 per cent. black. 43.10 minutes per hour when no smoke issued from the stack and an average percentage of 6.5 black smoke from observations. Observations on this same class show a maximum of 13.00 minutes per hour and a minimum of 0.00 minutes per hour smoke equal to or greater than 60 per cent. black. Maximum of 59.75 minutes and a minimum of 10.75 minutes per hour in which no smoke issued from the stacks; and a maximum of 16.0 per cent. and a minimum of 0.00 per cent. black smoke.

TABLE 9—*Summary of plant survey with smoke records.*

Fired by	Number of Plants	Fuel	Thickness of Fire	Number of Boilers Per Plant	Boiler Horsepower Per Plant	Type of Boiler	Nature of Load (1)		Smoke Records.				
							Uni-form	Vari-able	Number of Stacks	Per Cent of Black Smoke	Smoke equal to or greater than 60% black (2)	Stack Clean	Remarks
Hand	56	54 P'gh Coal 1 Low Volatile	3" to 24"	1 to 10	20 to	32 Horizontal return tubular			51	Average per hr. 23.4% Maximum 66.0% Minimum 0.3%	Average per hr. 12.2 min. Maximum 40.8 min. Minimum 0.0 min.	29.8 min. 52.8 " 0.0 "	These stacks are connected to boilers without fire tile roofs or coking arches over the fire
		1 Wood			2500	18 Water tube 3 Locomotive 3 Two Flue	30		11	Average per hr. 13.6% Maximum 25.0% Minimum 4.8%	Average per hr. 5.2 min. Maximum 13.5 min. Minimum 1.0 min.	34.5 min. 48.5 " 18.8 "	Boilers are equipped with Dutch ovens and with coking arches greater than 2'6" in length over the fire
Chain-Grate Stoker	33	33 P'gh Coal Slack or Nut and Slack in 23 Plants, run of mine in 10	4" to 8"	1 to 26	250 to 6500	All water tube 23 Horizontal Type 10 Vertical Type.	8		36	Average per hr 10.5% Maximum 51.0% Minimum 0.0%	Average per hr. 2.1 min. Maximum 27.0 min. Minimum 0.0 min.	37.6 min. 60.0 " 0.0 "	
Front feed Avalanche Type of Stoker	34	33 P'gh Coal Slack, nut & Slack, or Run of Mine & Slack in 21 Plants, Crushed Run of Mine or Nut Size in 13	3" to 24"	2 to 22	450 to 7980	All water tube Horizontal type in most cases	8	26	60	Average per hr 27.2% Maximum 63.0% Minimum 1.1%	Average per hr. 14.6 min. Maximum 57.5 min. Minimum 0.0 min.	22.8 min. 57.0 " 0.0 "	
Side-feed Stoker	19	Pgh coal in 13 plants. Youghiogheny in 1 plant Slack or nut and slack size fuel used in 13 plants. Run of Mine in 1 plant.	$2\frac{1}{2}$" to 12"	1 to 20	150 to 10,000	3 Horizontal Return tubular 15 Water Tube, 1 Fire Tube.	4	10	21	Average per hr 7.6% Maximum 29.0% Minimum 1%	Average per hr. 1.9 min. Maximum 9.0 min. Minimum 0.0 min.	43.8 min. 60.0 " 10.75 "	

Under-feed Stoker	10	Pgh Coal in 9 plants. New York and Cleveland. Gas Coal in 1 plant. Slack or nut and slack used in 9 plants and Run of Mine in 1 plant.	4' to 30'	1 to 12	85 to 1200	4 Horizontal Return Tubular 5 Water Tube 1 Scotch Marine	4	6	12	Average per hr. 6.5% Maximum 15.0% Minimum 0.0%	Average per hr. 1.35 min. Maximum 13.0 min. Minimum 0.0 min.	43.1 min. 59.8 " 10.8 "	

1. In a number of cases information on the nature of the load was not obtained.
2. An average of eight minutes per hour of smoke equal to or greater than 60% black constitutes a violation of the city smoke ordinance.

Appendix I.

Prevailing Winds.

The following table shows the prevailing winds and their velocities during the years 1911 and 1912 as observed at the Pittsburgh Station of the United States Department of Agriculture Weather Bureau.

PITTSBURGH—DIRECTION OF WIND.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1911	SW	NW	W	NW	NW	NW	NW	NW	NW	NW	W	SW	NW
1912	W	W	NW	SW	W	NW	SW	SW	SE	NW	W	SW	W-SW

VELOCITY OF WIND IN MILES PER HOUR.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1911	11.5	13.4	15.3	12.8	9.3	10.0	8.5	9.0	9.2	9.3	15.0	11.1
1912	13.7	12.8	11.8	14.6	11.3	9.9	8.5	10.1	9.2	9.9	14.1	13.6

Appendix II.

Powdered Coal.

The value of powdered coal as fuel, when applied to steam boilers and metallurgical processes has long been known, and appliances for pulverizing and feeding the coal have been on the market for many years. However, despite its many apparent advantages and the simplicity of the process not much progress has been made towards its general adoption, especially as applied to the steam boiler. This is probably due to the fact that no apparatus has yet been perfected which will warrant the adoption of this process in regular plant operation.

The operation of feeding and burning the fuel is very simple in principle, consisting in the most successful systems in reducing the coal to a very fine powder and injecting it by mechanical means into a furnace, lined with refractory material, along with the necessary amount of air for combustion. During the injecting process the powdered fuel is intimately mixed with the proper amount of air and combustion takes place with total absence of smoke. This process is not subject to the disturbing influence of an excess of air which accompanies the firing of lump coal. The carbon is thus maintained at its ignition temperature while floating in the air supplied, and until its combustion is completed.

The use of powdered fuel is generally confined to high volatile bituminous coals, due to the ease with which these fuels ignite. It has been found that only with exceeding considerable care in operation, can anthracite and the low volatile bituminous coals be used, because these fuels contain high percentages of fixed carbon. The low volatile bituminous coal and the anthracite coal burn slower and even a most gentle draft will cause much of the fuel to pass through the furnace unconsumed.

In the most successful systems for burning powdered coal only sufficient draft is induced to move the gases toward the chimney, the air required for combustion being forced mechanically into the furnace simultaneously with the fuel. By employment of this means more time is available for the combining of the fuel. The very low draft required eliminates the necessity for the construction of a tall stack.

The usual practice followed out in the construction of furnaces, for the burning of powdered coal, is not to place any baffle or bridge walls in the direct path of the gases where they have any appreciable velocity. These walls are, however, usually placed from twelve to fifteen feet from the burner. Coal is preferably used dry, as wet coal not only has the effect of retarding combustion, but also gives trouble in handling. The fuel is sometimes dried before it is crushed by passing it around a flue through which the chimney gases are drawn.

To obtain the best results in the firing of powdered coal, the coal must be reduced to a fineness so that 75 per cent. will pass through a sieve of 200 mesh, and 95 per cent. through a sieve of 100 mesh. To accomplish this result there are various types of grinders in use, but classified mainly according to two general systems. In the first type the fuel is ground by large machines in separate buildings, stored and supplied to the furnace as required; the necessary amount of air for combustion is blown into the furnace with the fuel. In the other types the fuel is first crushed to nut size, fed to the hoppers at the front of the boiler, here it is pulverized and then fed to the furnace with the required amount of air for combustion.

When properly operated, brick work of the highest quality is required to withstand the intense heat developed, as ordinary firebrick is soon reduced to slag by the high temperatures attained. A good quality of firebrick will withstand the action of the heat for some months without repair or renewal, provided the furnace is properly constructed and not subject to alternate effects of heating and cooling, which cause the brick work to crack.

Excellent results have been obtained by constructing these furnaces of brick made from carborundum slag, but the cost prohibits their general use.

The main advantages in the use of powdered fuel may be summed up as follows:

1. Complete combustion and total absence of smoke, when this process is carried out in a properly designed and operated furnace.

2. Losses due to excess air and cooling of furnaces by opening of fire doors are reduced to a minimum.

3. Use of a cheaper grade of bituminous coal, as impurities have very little effect on the successful operation of the process.

4. The ability to meet sudden changes in load, and reducing to a minimum the labor inherent to firing.

Among the disadvantages are:

1. Danger inherent to the storage of large quantities of powdered fuel ,giving rise in most cities to the enacting of laws prohibiting the storage of large quantities of this fuel.

2. Inability to secure, at a moderate cost, a satisfactory material to withstand the intense heat developed when operating this type of furnace properly.

3. Tendency of the stronger drafts to carry the fuel through the furnace unburned.

The application of this process to the steam boiler has no doubt largely been hampered by the fact that the maintenance cost in daily operation is high, due to rapid deterioration of brick work. The reliability of all devices. as vet applied to boilers, is questionable. It is claimed that savings of 40 per cent. have been made when powdered coal was applied to metallurgical processes, such as puddling, heating and reheating furnaces, and that smokeless operation was obtained in all cases.

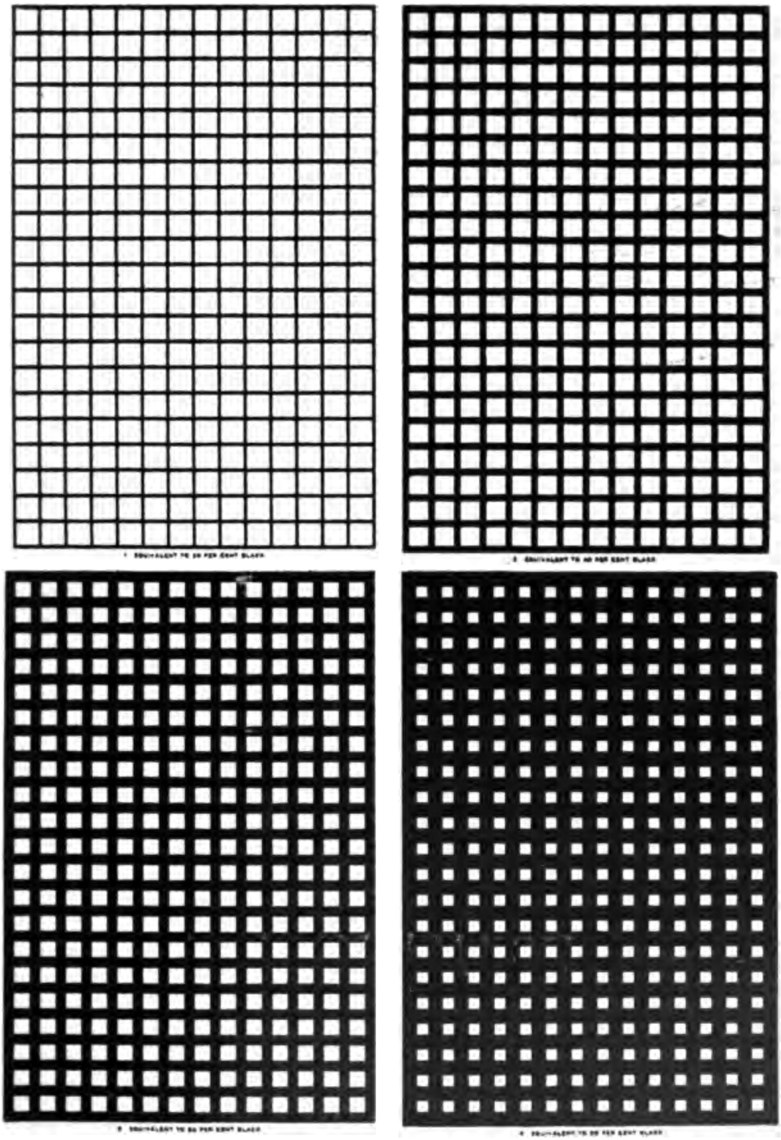

Figure 63—Ringleman Smoke Chart.

Appendix III.

The Construction of the Ringleman Smoke Chart.

A rule by which the cards may be produced is given by Prof. Ringleman as follows:

Card 0. All white.

Card 1. Black lines 1 mm. thick, 10 mm. apart, leaving spaces 9.0 mm. square.

Card 2. Lines 2.3 mm. thick, spaces 9.0 mm. square.

Card 3. Lines 3.7 mm. thick, spaces 6.3 mm. square.

Card 4. Lines 5.5 mm. thick, spaces 4.5 mm. square.

Card 5. All black.

These lines and spaces are so arranged that the black covers respectively 0, 20, 40, 60, 80 and 100 per cent. of the white surface of the card. These percentages are graded for convenience as smoke numbers 0, 1, 2, 3, 4 and 5, so that number 0 signifies no smoke or a clean stack; and number 4 signifies a stack which is emitting an 80 per cent. black smoke, or for convenience the percentage of black smoke can be obtained by multiplying the smoke number by twenty per cent.

Methods of Taking Smoke Readings.

In making observations of the smoke proceeding from a chimney, four cards ruled like those in Figure 63, together with a card printed in solid black and another left entirely white, are placed in a horizontal row and hung at a point 50 feet from the observer, and as nearly convenient in line with the chimney. At this distance the lines become invisible, and the cards appear to be of different grades of gray, ranging from very light gray to almost black. The observer glances from the smoke coming from the chimney to the cards which are numbered

from 0 to 5; determines which card most nearly corresponds to the color of the smoke, and makes a record accordingly, noting the time. Observations should be made continuously during, say one minute, and the estimated average density for that minute recorded, and so on, records being made once each minute. The average of all the records made during the period of observation is taken as the average figure for the smoke density.

Readings of one hour or longer in duration were made on each stack observed in the survey and the density of the smoke issuing from the stack tabulated each quarter of a minute according to the method specified. To determine the total number of minutes that any one grade of smoke was emitted from a stack, the number of readings of smoke intensity of this grade were taken and divided by four, thus giving the smoke minutes. To determine the per cent. of black smoke from readings taken, or average smoke density, the following rule was followed:

$$\text{Percentage of density} = \frac{\text{Smoke Units} \times 0.20}{\text{Stack Minutes}}$$

Appendix IV.

Rules to Aid in Abating Smoke and to Increase Efficiency With Hand Firing.

1. Fire evenly and regularly.
2. Fire moderate amounts of coal at a time and place the coal where it is needed.
3. Keep the fire clean, even, and bright all over; do not allow it to burn into holes or thin spots.
4. Break up the lumps and have the coal as nearly as possible uniform in size. Do not fire any lumps larger than a man's fist.
5. When a fire has burned into holes, do not throw green coal on the bare grates, but push incandescent fuel into these spots before firing.
6. Regulate the draft, and air supply to suit the fire.
7. Watch the condition of the fire and the steam gauge together. Do not fire large quantities of coal.
8. Do not level or stir the fires unless absolutely necessary, and then use the utmost care.
9. Do not allow ashes and clinkers to accumulate on the side or bridge walls, as this cuts down the effective grate, area and causes other troubles.
10. Do not allow too long intervals between firings.

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Bulletin No. 1. Outline of the Smoke Investigation. 16 p. Free.

Bulletin No. 2. Bibliography of Smoke and Smoke Prevention. 164 p. Fifty cents.

Bulletin No. 3. Psychological Aspects of the Problem of Atmospheric Smoke Pollution. 46 p. Twenty-five cents.

Bulletin No. 4. The Economic Cost of the Smoke Nuisance to Pittsburgh. 46 p. Twenty-five cents.

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Mellon Institute of Industrial Research and School of Specific Industries

Smoke Investigation Bulletin No. 9

Papers on the Influence of Smoke on Health

Edited by
Oskar Klotz and Wm. Charles White

University of Pittsburgh
Pittsburgh, Pa.
1914

The Institute

Table of Contents

Introduction

The present bulletin contains the papers representing the work done by the physicians and laboratory investigators on the Staff of the Smoke Investigation.

Much difficulty was experienced by the physicians in arriving at definite conclusions, because the present state of our knowledge does not admit of satisfying and positive pronouncements of the relation of smoke to diseases of the eye, ear, nose and throat and other diseases requiring surgical intervention. The psycological aspects of the problem have been discussed by J. E. W. Wallin, Ph. D. in Bulletin No. 3 of this series.

Doctor Cohoe has prepared his resume of the literature especially for this bulletin. The papers of Doctors Klotz, Holman, Haythorn and White have all been published or read elsewhere in scientific circles.

Doctor Cohoe's paper gives a review of the history of the thoughts and work of men leading up to our present knowledge and attempts no decision of the vexed problems.

The work undertaken by Doctor Klotz deals with the gross pathological changes which arise from the excessive inhalation of a carbon-laden air. Whereas the presence of small quantities of smoke has no harmful effect upon the tissues, it is shown that the continuous accumulation of carbon may act quite differently. This feature alone in our problem deserves further attention.

The work of Doctors Haythorn and Holman are both very valuable contributions to this subject, containing the results of original research that aid greatly our search after the truth of the relation of smoke to health. Doctor Haythorn's paper brings out some suggestive points in indicating the histological changes induced by smoke and their relation to pneumonia.

It will be seen in reading all of these papers that practically all investigators whose opinions are based on

grounds other than theory, are agreed that smoke has a tremendous influence in increasing the incident severity and mortality of acute diseases of the air passages. It would appear that this increased susceptibility is, in part, the result of the lowering of our natural body resistance. In simple terms, the smokier the atmosphere, the more the colds and bronchitis, and the more money paid to doctors.

On the other hand, the relation of smoke to tuberculosis is one of greatly divided opinion and the burden of proof is that if smoke has any influence at all, it is not a harmful one. The work of Doctor Klotz and of Doctor Haythorn offers some explanation of this probability. If this be the truth and tuberculosis is not influenced by smoky atmosphere, it is time to stop the utterance of this popular fallacy which can do naught other than harm in sacrificing the confidence of the public in those who should guide them.

We feel very sure that a careful perusal of this bulletin will fully repay every reader of it.

Wm. Charles White.

The Relation of Atmospheric Smoke and Health

B. A. Cohoe, AB., MB.
Pittsburgh, Pa.

INTRODUCTION.

In the present paper an attempt has been made to call from scientific literature the evidence, pro and con, which has been adduced by various scientists whose opinions would seem to merit consideration, concerning the role played by a smoke-laden atmosphere upon the bodily health of the community.

Thanks to the triumphs of the modern science of sanitation, a successful assault has been waged against such water-borne diseases as typhoid fever and cholera by a close surveillance of the water supply and sewage disposal within our cities, while, more recently, the efforts of the Public Health Bureau have rendered it possible for our citizens to obtain pure food stuffs, free from adulteration. Meanwhile, strangely enough, the problem of pure air has received but scanty consideration.

This omission appears the more astounding when regarded in the light of a fact stated by Cohen that every man and woman breathes about two thousand gallons of air in twenty-four hours, or about thirty-four pounds in weight, as contrasted with a daily intake of five and one-half pounds of liquid and solid foods. Or, in other words, the weight of the air inhaled daily is more than six times the weight of the daily consumption of food.

Fortunately, within recent years, largely owing to the organization of Smoke Abatement Leagues, an agitation has been begun advocating an examination of the air in a manner comparable to the careful scrutiny now required for our water and food supplies and of the sewage disposal.

In a survey of the various factors which tend to contaminate the atmosphere of cities, smoke is conceded by all to be the greatest source of pollution. The Smoke Abatement Leagues, in their efforts to purge the air of this menace, have encountered numerous obstacles, notably an apathetic public and a certain antagonism on the part of manufacturers against any attempt to curtail the amount of industrial smoke. The lethargy of the public in regard to the smoke evil doubtless has arisen from the circumstance that, until recently, the opinion has prevailed in the minds of the laity, and indeed of physicians as well, that a smoky atmosphere is not only not injurious but at times even beneficial to the public health. This supposition gained favor from an observation, largely erroneous, that coal miners are not prone to contract tuberculosis.

A belief in the antiseptic qualities of smoke has been entertained by many physicians for several centuries. It is a matter of historical interest that during the Plague Year in London fires were kept burning in the hope of suppressing the epidemic for "it was alleged that the sulphurous and nitrous particles that are often found to be in the coal, with the bituminous substance which burns, are all assisting to clear and purge the air and render it wholesome and safe to breathe in."

Quite apart from any mooted question as to the ultimate effect on health, the citizens of Pittsburgh have, for many decades, been keenly alive to the bodily discomfort resulting from the omnipresent smoke pall in the community. As early as 1804, General Neville, the then Burgess of Pittsburgh, is quoted (O'Connor) as having stated with reference to the smoke nuisance "that not only the comfort, health, and in some measure, the consequence of the place, the peace and harmony of the inhabitants, depend upon speedy measures being adopted to remedy the nuisance." Nor, indeed, were visitors, then as now, slow to observe the baneful influence of the smoke upon the inhabitants for, in 1818, Eswick Evans wrote that "'owing to the exclusive use of coal here, both by the man-

ufacturers and by private families, the whole town presents a smoky appearance. Even the complexion of the people is affected by this cause." Major Forman noted in 1797 that "the coal smoke is such as to affect the skin of the inhabitants." Another writer of note who corroborated these observations was Henry Bradshaw Fearon, a London surgeon, who, in 1817, remarked of Pittsburgh that "the smoke is extreme, giving to the town and its inhabitants a very sombre aspect."

Such casual observations, extending over a period of more than a century, only serve to emphasize a deplorable degree of apathy on the part of the citizens in tolerating a nuisance whose injurious effects have been so long and so clearly proclaimed. Yet Pittsburgh fares no more ill than many of the large industrial centers of the world with respect to the smoke evil.

In the present resume of the literature, the aim has been to present an analysis of the vital statistics, special investigations, and experimentations bearing upon the problem of the relation of smoke and health, and no attempt has been made to deduce other than a few generalizations concerning local conditions in Pittsburgh. A special study of the local conditions and vital statistics from a viewpoint of the status of smoke as a possible factor in increasing the local death rate has been reserved for another bulletin of the present series.

I.

EVIDENCE FAVORABLE TOWARDS SMOKE.

In a general survey of the literature concerning the role of smoke in the causation of disease, it is not surprising that an expression of doubt concerning the harmfulness of smoke in the community should be encountered in certain quarters, nor, indeed, that certain scientists should entertain a sentiment favorable towards smoke. While the smoky atmosphere of an industrial center continues to be the index of the prosperity of the town, the community is likely to overlook the discomfort and danger of the same and foster any attempt to defend its antiseptic qualities. In an impartial weighing of the evidence, pro and con, regarding smoke such favorable opinions, coming from observers whose authority cannot be overlooked, merit consideration.

The popular idea that smoke does not act injuriously on health, but only uncomfortably, has served to retard in no small measure the work of smoke abatement. Our standard works on hygiene take little or no cognizance of the harmful effects of smoke. Many authors, who do not regard smoke as injurious, attempt to establish their claim by a citation of the low death rates of certain industrial towns. At the Manchester meeting of the Smoke Abatement League of Great Britain, 1911, a delegate made the assertion that his town (Coatbridge, a smoky industrial town) was one of the healthiest of towns, admitting, however, that the smoke was at times very annoying. The reason for his defense was obvious in his statement that "furnaces did make smoke and to prohibit the making of smoke would prohibit the making of puddled iron." A writer in the Revue Industrielle (November, 1899) voices the same sentiment in stating: "In spite of the abundance of smoke, people are no worse off in Leeds than elsewhere.

Facades of houses are soiled but the inhabitants do not suffer. Are we going to learn one of these days that smoke, thanks to its antiseptic properties, contributes to making the atmosphere healthful?"

The medical profession, indeed, has at times given utterances to similar opinions. At a conference held in the Franklin Institute, Philadelphia, a few years ago a physician is quoted as saying: "I do not mean to intimate that the smoke nuisance injures health in any ordinary sense; on the contrary, I am inclined to think that the essence of this, which is always a minute amount of free carbon in the air, is rather healthful than otherwise." Similarly, following a discussion of the smoke evil at a meeting of the Philadelphia County Medical Society, 1906, it was recorded, "that the nose, throat and eyes are directly injured by smoke was admitted beyond a doubt, but whether the presence of soot in the human lungs is an indifferent matter, or an injury, was left undecided. There is little evidence to show that the presence of smoke in the air increases the morbidity or the mortality of the community."

In a study of anthracosis as a factor in the causation of lung diseases, Trotter has commented upon the rarity of pulmonary tuberculosis among miners, and from his observations he was lead to regard coal dust as productive of little, if any, harm to the organism. His conclusions would seem to show that coal dust renders miners more or less immune to tuberculosis.

1. Coal dust may remain imbedded under the skin for years without producing any irritation whatever.

2. The death returns from phthisis in a colliery district show a greater proportion of deaths among females than males.

3. Colliery surgeons almost invariably state that phthisis is not so common in mining as in other districts.

4. In the majority of phthisis cases which do occur, there is a strong family history on one or both sides.

So popular has been this fancy that coal dust acts beneficially in pulmonary tuberculosis that it has been for years a common custom for persons affected with this disease to resort to coal mines, or to build fires and inhale the smoke, hoping thereby to affect a cure, on the quasi-scientific supposition that the inhaled carbon promoted healing. As will be shown later, more careful recent investigation has demonstrated the fallacy of this supposition and has placed a revised interpretation on the apparent low death rate of miners from tuberculosis.

II.

EVIDENCE OF A DOUBTFUL NATURE.

In a second grouping can be assembled the opinions of a number of scientists who, while they would be constrained to regard smoke as a cause of ill health, yet in a spirit of scientific conservatism consider the case as not proven. The study of the problem of the effect of smoke upon health presents many complicating factors, which render judgment difficult.

Among these, Mehl states that "no one has yet shown that smoke and fog are injurious to health," but the same writer proceeds to demonstrate by means of statistics that the increased death rate from respiratory diseases, in large industrial centers, must be referred to the influence of smoke and dust. Cohen, one of the most active workers in the crusade against industrial smoke, while realizing that it is quite true that pulmonary disease is much higher in towns than in the country, concedes that "we cannot single out smoke as the cause, because the problem is complicated by so many other factors."

Another writer, Glinzer, while regarding smoke as truly injurious to health in a degree not as yet determined, appreciates its twofold qualities. Smoke, he believes, possesses excellent germicidal and disinfecting properties. "Obnoxious vapors and other harmful products carried by the air are absorbed and retained by the material elements of smoke, and are finally carried away harmlessly by the rain, so that smoke, on the contrary, can be stamped as a purifier of the atmosphere and a benefactor of the human race. In my opinion, this is doubtless true; it is only a question of which influence is the stronger. I believe we can safely depend on our instinct, and this tells us decidedly that smoke does not agree with us."

Another careful investigator who regards the proof as incomplete is Rubner. He believes that while there can be scarcely any doubt of the possibility, perhaps even the probability, that the smoke content of the air is an important element of injury to health; a matter of the coincidence of bad air and disease is another matter. "Such a proof can scarcely be attained even by the standard of very exact etiological investigations. If there is an entire lack of knowledge as to how the pollution of the air by smoke is distributed in the country in general, and as to whether the regions with impure air coincide to some extent with those of more frequent lung diseases, there is still further lack of proof as to whether the condition of the air is alone responsible for the injury, or whether the remaining within doors does not also contribute to it. The injuries resulting from a pollution of the air might also be traced to climatic influences."

III.

EVIDENCE OF A POSITIVE NATURE.

Passing over the foregoing evidence, which is more or less equivocal in kind, we come to the evidence of a more positive nature, which has been gleaned from the many monographs appearing in the literature dealing with the smoke problem, in which the authors have attempted to establish proof concerning the pernicious influence of smoke and its constituents upon the individual and public health. In this connection, the significant fact is revealed that the more exhaustive the investigations undertaken by the various scientists, from the viewpoint of sanitation, vital statistics, and animal experimentation, by so much the more do the conclusions evolved attest the deleterious effect of smoke on health. Such observations have been made from many angles—the effect of smoke as a whole, and the effect of its various ingredients, as well as what may be regarded as the direct primary effect together with the more remote secondary effects of a smoke-laden atmosphere. Dealing first, therefore, with the opinions promulgated as to the general effect of smoke, or the influence of smoke as a composite entity upon the health of the community, we shall pass to the evidence obtained as to the effect of the various constituents of smoke, such as carbon, soot, and gaseous elements upon the human organism, and finally, to the indirect effects of smoke in impairing the health of a community.

(A) The Effects of Smoke as a Whole.

The general effects of a smoky atmosphere upon the health of inhabitants have been broadly summarized by Wainwright, who states that smoke interferes with the welfare of a community—

1. By conducing to the formation of fog and rain.

2. By shutting out sunlight and depriving us of certain qualities of light of great importance in regard to changes in organic matter.
3. By depositing soot and rendering houses or their contents dirty.

Moreover, with respect to the individual he believes the acid content of smoke and the irritating particles suspended in it are harmful to the tissues of the nose, throat and eyes, and especially the lungs and air passages whether these be in a healthy or other condition. He further indicts smoke as a menace indirectly to the sick of a community, averring that "it aggravates to the discomfort of those suffering from all forms of heart trouble; increases the distress of those who have nervous complaints; lowers the tone of general health; is a peril to the aged; diminishes buoyancy of spirit as well as reducing still further an already lowered resistance to disease."

Valuable evidence has been presented by a number of Medical Health Officers of smoky industrial cities concerning prevailing health conditions. This is especially true of the city of Manchester which may well be selected as a type of smoky towns. Concerning local conditions in the city, Dr. Niven, M.H.O., has written: "Manchester is still conspicuous for its high mortality, and it is especially conspicuous for its excessive death rate from phthisis, pneumonia, bronchitis, and heart disease. All forms of septic disease are unduly prevalent. The windows of houses and factories are closed on account of the dirt which enters by the open window. Less attention is paid to cleanliness than is needful for health. Fresh air is needed not only in the treatment of consumption, but is equally necessary for the raising of healthy children. * * * There has been a great advance in the physical well-being of the population, but the death rate is still among the highest prevailing in great towns. Manchester, like other towns, exhibits an immense improvement as regards some diseases, more especially smallpox, enteric fever, and scarlet fever. * * * The mouth breather is at a much greater disadvantage in Manchester

and the large towns than he is in the country and it is important that adenoids should be attended to."

The report of Dr. Tatham, M.H.O., in 1890, speaks even yet more strongly of the local conditions in Manchester. This writer states that the working life of the people in central Manchester is curtailed by ten years. To quote from his report: "Our people lose 30% of their lives. * * * The acids of smoke and carbon particles operate upon the lungs for years before they finally destroy them."

If the criterion of physical fitness for army service may be taken as an index of the health of the citizens of a smoky city, the statistics for Manchester, according to Horsfall, reveal an appalling condition. This author writes: "In Manchester in 1899 of 11,000 men who wanted to enlist only 9% were found to be physically fit for the regiments of the line, and at the present moment the Navy could only accept 14% of the boys belonging to all grades of society who wanted to join. There are no figures among races of the world comparable with these in their revelation of physical deterioration."

Among the numerous investigations which have been undertaken to determine the direct effect of smoke as a source of ill health, it is not surprising to find that the burden of proof has been sought in the relation of smoke to diseases of the respiratory organs, since the lung tissue is necessarily first invaded by the smoke content of the air inhaled. Accordingly, the majority of observers have based their studies upon the incidence of lung disease in smoky industrial cities. While vital statistics may not furnish, perhaps, the ideal criterion of the health of a community, they afford without doubt the most readily available standard of comparison.

In reference to the irritating effect upon the lung tissue of the constant breathing of a smoky atmosphere, Reed writes: "The slight morning cough with the equally slight expectoration of black mucus is an experience familiar to denizens of a smoky town, but an experience which, to the medical mind, suggests a persistent although

slight irritation of the upper air passages that are thus made hospital avenues for tuberculous infection."

Supfle, another observer, corroborates the opinion of the former writer in saying: "Climate has much to do with the effects of smoke on health. Southern cities, with warm climate, do not suffer so much as those in the north. Cities lying in the valleys suffer most. The acids given off in fumes provoke a hypersecretion of the mucous glands of the trachea and bronchi. In time, one accommodates oneself to the new conditions and one apparently feels well. And herein lies the great danger, as one ceases to cough and outward symptoms no longer appear, the injurious effects remain."

According to statistics cited by Wainwright, the death rate from diseases of the respiratory organs in Manchester was in 1874, 7.7, and in 1893, 23.2 per 1,000 of deaths from all causes; and in Westmoreland, England, the death rate from the same diseases was but 2.29 in 1888, and 13.7 in 1893. These increased death rates he charges to an increased consumption of coal and consequent smoke.

Russell has utilized the following comparative table to show the extreme frequency of death due to lung diseases occurring in and about the smoky atmosphere of Glasgow in the year 1880:

	Contagious Diseases	Lung Diseases	Other Diseases	Total
Rural Districts	289	354	996	1,639
City of Glasgow	773	1,024	1,232	3,029
Thinly populated part of Glasgow (36 persons per acre)	450	600	870	1,920
Densely populated part of Glasgow (512 persons per acre)	1,020	1,860	1,600	4,480

Similarly, a table compiled for Manchester reveals a strikingly high incidence of deaths from respiratory diseases. The death rate in different parts of Manchester

per 100,000 for the year ending the third quarter of 1891 was as follows:

	Contagious Diseases	Lung Diseases	Other Diseases	Total
Thinly populated part	241	534	954	1,729
Densely populated part	510	1,544	1,798	3,752

Concerning southeast Lancashire, a smoky industrial center, Dr. Brown states that the death rate in that district from respiratory diseases is very considerably higher than in the southern and western parts of the country.

Far and away the most comprehensive study of the direct effect of smoke upon the respiratory organs has been made by Dr. Louis Ascher of Konigsberg. He has published several monographs dealing with the subject both from the standpoint of vital statistics and animal experimentation. His conclusions, while not universally accepted, have been drawn from the most careful scientific investigation of the problem of smoke and health yet presented. His work merits more than a passing survey.

In pursuing his observations, Ascher utilized the statistics of the Imperial Health Bureau of the German Empire. Respiratory diseases he separated into two main groups, the tuberculous (designated T) and the non-tuberculous (NT). In some instances the German statistics were compared with those of other countries, as England and America. A study of these statistics, dating back to 1875, lead him to conclude that since 1875 there has been an increase in acute inflammatory diseases of the respiratory organs. The possible bearing of a diminished power of resistance, or of climatic or infectious causes, as contributing to this increase was considered by the author, but each of these in turn were found not to be a factor in the increase of acute lung diseases. Was this increase confined to Prussia during this period? An examination of the mortality tables gave a negative answer and revealed a similar increase in the whole of Germany, as well as in England and America. In the latter countries he found

an increase in the death rate from pneumonia between 1890-1900 of 186.9 to 192 of every 100,000 of the population. He made a study of conditions in agricultural districts where he found a lowering of the death rate from tuberculosis and a rise in acute lung diseases. His conclusion from his earlier statistical studies was as follows: "The increase in the mortality of acute lung diseases must be the result of some harmful factor which, it is true, is found in agricultural communities, but with a much higher increase in industrial centers. This factor is not limited to the places of industrial work but is also found in the homes, as proven by the mortality tables for infants and old people. The cause of this increase can only be the smoke of the coal fires."

Ascher was fully cognizant of the opposition that such conclusions might engender on the part of the critics. The lethargy of the public in regard to the smoke problem has been due, he believes, to the fact that smoke has not been considered harmful. The reasons why smoke has not been regarded as a menace he summarizes as follows: (1) Coal smoke does not act as an irritant, causing discomfort or inflammation on the body tissue with which it comes in contact, as does ordinary dust. And since there is relatively little coal dust in the air, it is inconceivable that it should have much pathological effect. (2) The researches of Arnold tended to show very slight harmful effects from coal dust in comparison with other forms of dust. In answer to these contentions, Ascher asserts that the action of smoke cannot be represented as an inflammatory one due to mere physical ingredients. Since smoke consists in the greater part of chemical ingredients, the effect upon the human lungs is rather an indirect than a direct one, due to the fact that the normal constituents of the air are replaced by abnormal ones. In order to obtain relevant statistics concerning the effect of smoke upon health, it is necessary to assume that smoke belongs to the same category of harmful agents which have an indirect predisposing effect, such as alcohol, unsanitary dwellings, etc.

Another reason which has been urged against the harmfulness of smoke has been the fact that coal miners show an especially favorable death rate from tuberculosis. According to statistics, very few miners die from tuberculosis. Ascher claims that an explanation of this can be found in the fact that they die of acute lung diseases. The death rate among miners from acute lung diseases is much higher than among other inhabitants of the same age in Prussia. Again, he states, every miner becomes within forty years an invalid and is then no longer considered in the statistics. From this apparently low death rate from tuberculosis amongst coal miners has arisen the belief that coal dust, smoke and soot were not only not harmful but even beneficial to health. Ascher has compiled the following table to show the fallacy of this view:

TABLE I.

FIFTY-FIFTH ANNUAL REPORT OF THE REGISTRAR GENERAL OF THE UNITED KINGDOM.

Death Rate per 10,000.

	T.	NT.
Laborers in Agricultural Districts	18.8	18.6
Coal Miners	14.10	32.6
Chimney Sweeps and Soot Merchants	37.1	43.1
Coal Heavers	29.7	65.6

Here it is apparent that, while the death rate from tuberculosis appears low among coal miners, it is not low among other laborers working in coal dust and smoke. Coal carriers, chimney sweeps, and soot handlers show a high mortality both from tuberculosis and non-tuberculous disease. Ascher maintains that the low mortality from tuberculosis among coal miners is due to the choice of picked workmen, selected for hard work, and who earn a higher scale of wages and live under good social conditions. Hence, the better physical and economic conditions of coal miners serves to explain the low death rate from tuberculosis. These same conditions ought to reveal a

lower mortality from non-tuberculous lung diseases, but as a matter of fact the death rate from such diseases among miners is far above the average.

From German statistics, Ascher found a similar state of matters among coal miners.

TABLE II.

Death Rate per 10,000.

	T.	NT.
Workmen in Prussia (15-60 yrs. of age)	28.8	16.5
Coal Miners in the Ruhr District	13.1	39.2

Here, again, Ascher explains the low death rate from tuberculosis among miners as due to the fact that they are very robust and earn high wages. The high death rate from non-tuberculous lung disease is again very striking.

Statistics of the mortality from tuberculous and non-tuberculous lung diseases for the whole population of Prussia are given in the following table:

TABLE III.

Death Rate per 10,000 of Population.

	T.	NT.
1875-1879	31	16
1880-1884	31	20
1885-1889	29	22
1890-1894	25	22
1895-1899	21	26
1900-1904	19	27

This table shows for Prussia a striking decrease in the death rate from tuberculosis and an increase in other acute lung diseases.

He further compared the death rate of infants in agricultural and industrial districts of Prussia:

TABLE IV.

	East Prussia (agricultural)			Silesia (industrial)			Rhine Province (industrial)		
	NT	S&M	D	NT	S&M	D	NT	S&M	D
1876	4.0	3.1	13.7	3.4	10.9	4.4	3.7	2.1	2.8
1880-81	1.6	4.7	34.9	5.0	8.7	5.5	6.4	3.4	3.6
1885-86	3.4	18.2	30.3	7.3	7.8	8.6	12.2	4.1	2.6
1890-91	4.2	9.9	25.0	10.7	4.1	7.9	15.3	2.3	2.1
1895-99	5.9	7.4	13.9	15.2	3.9	3.2	16.7	2.7	2.2
1900-01	6.9	7.1	10.5	19.4	6.4	2.7	21.2	2.8	1.6

S. (Scarlet Fever.) M. (Measles.) D. (Diphtheria.)

An analysis of the death rate of infants under one year of age for the period 1876-1901 in certain rural districts and industrial districts of Prussia showed the following:

Death Rate per Hundred Under 1 Year of Age.

	NT.	Scarlet Fever, Measles, Diphtheria, Croup.
In six rural districts of East Prussia	4.3	29.8
In six industrial districts of Rhineland	12.6	5.2

He points out here that the contrast between acute lung diseases and contagious diseases among those who are most subject to them, viz., children under one year of age, is very great. This table proves that the higher death rate from acute lung diseases in the Rhenish districts is not due to worse economical conditions nor a more unfavorable climate, for the six districts of East Prussia have a considerably poorer population than the six industrial districts of Rhineland. The former also have a

longer and harder winter and a climate subject to great variations of temperature, whilst the six Rhenish districts have a mild and even temperature. Here, he states, we see a rapid rise of NT diseases, both in the Silesia and the Rhine industrial districts, an increase of from 500% to 600% during a period of 25 years. That such increase is not merely an expression of increased opportunity for infection is clearly proven by the varying behavior of the death rate from the infectious diseases, scarlet fever, measles and diphtheria, the death rate from the latter being highest in the agricultural regions of East Prussia and much lower in the industrial regions.

The death rate of infants in rural and urban districts is again compared in the following table:

TABLE V.

	NT.		Acute Infectious Diseases	
	Male	Female	Male	Female
Country	6.24	5.19	25.37	23.81
Small Town	12.61	10.52	18.10	17.75
Medium Sized Town	17.33	15.34	11.36	11.48
Large City	26.30	23.34	10.52	10.52

This table shows significantly an increase in acute lung diseases and a decrease in infectious diseases.

The mortality of infants from acute lung diseases for a period of years in the whole of Prussia is shown in the following:

TABLE VII.

Death Rate per 1,000.

	Male	Female
1876-1879	8.3	6.9
1881-1884	11.6	9.6
1885-1889	13.1	10.9
1890-1894	17.3	14.5
1895-1899	20.2	16.2
1900-1909	22.10	17.7

This constant increase in the death rate among infants Ascher believes can be attributed to the increase in smoke. Smoke and soot in small quantities decrease the resistance, especially in weakened individuals, *i. e.,* infants and the tuberculous.

For the purpose of comparing the rates of death for tuberculous and other acute lung diseases, Ascher has taken some statistics from England:

TABLE VIII.

Deaths in England for Every Million of Population.

Years	1850-4	1855-9	1860-4	1865-9	1870-4	1875-9
Tuberculosis	3655.0	3448.0	3367.6	3326.0	3013.4	2903.0
Acute Lung Diseases	2769.0	3155.2	3409.2	3415.4	3607.2	3981.0
T : NT.	1.34	1.09	0.99	0.97	0.84	0.75

Another table for a later period shows:

TABLE IX.

	1881-85	1886-90	1891-95
Tuberculosis	18.30	16.24	14.63
Bronchitis, Pneumonia, Pleurisy	32.09	33.22	33.63
T : NT.	0.57	0.49	0.43

Both tables show a progressive decrease in the ratio, a lowering of the death rate from tuberculosis, and an increase in acute lung diseases.

Ascher's next step was to undertake a comparison of the death rates in smoky and textile districts. He cites the work of Finkelburg, who showed that the mortality from affections of the bronchial tubes is more than half as great again in towns as in the country and, moreover, that it rises to an unusual height not in textile towns, but in places where coal is burned. Ascher's own investigations corroborated the findings of Finkelburg. He con-

trasts the statistics obtained for Krefeld, a typical textile town, and Essen, a smoky town.

TABLE X.

	Krefeld (Textile)			Essen (Smoke)		
	T	NT	T:NT	T	NT	T:NT
1876	5.92	0.61	9.7	4.70	1.18	4.0
1880-81	4.87	1.48	3.2	4.21	3.37	1.2
1885-86	5.37	1.49	3.6	3.66	4.12	0.9
1890-91	3.83	2.81	1.4	2.98	4.48	0.7
1895-96	3.10	2.49	1.2	2.12	3.79	0.6
1900-01	2.37	2.50	0.9	1.91	5.05	0.4

He concludes from this that we always find tuberculosis in textile districts and acute lung diseases in smoky districts.

He has employed the following table, taken from statistics of the Royal Prussian Offices, to show that the mortality from acute lung diseases is 30% higher in smoky than in textile districts:

TABLE XI.

Mortality per 1,000 of Population.

	T	NT	T+NT	T:NT
Textile Districts	1.83	2.23	4.06	0.82
Smoky Districts	1.77	2.93	4.70	0.62

A selection of a group of non-industrial and industrial districts has offered a striking contrast of the frequency of non-tuberculous and tuberculous mortality in the two classes. The statistics are taken for the period 1898-1907.

TABLE XII.

Death Rate per 10,000.

Non-Industrial Area			Industrial Area		
	NT	T		NT	T
Amsberg	28.19	23.59	Dortmond	36.88	14.99
Meschede	26.99	27.35	Bochum	35.89	13.78
Brillon	24.50	29.36	Gelsenkirchen	37.35	15.20

In analyzing this table, Ascher points out that the three industrial districts are wealthier and, for that reason, presuppose a lower death rate from tuberculosis, but they also have a more smoky atmosphere and therefore a higher death rate from acute lung diseases.

For the purpose of establishing the fact that this pernicious influence of smoke is active at all stages of life in increasing the death rate from acute lung diseases, he has compared the statistics from two equally large towns, situated in close proximity, in the industrial district of Westphalia. These towns are built in the same style and differ only in the amount of coal smoke in the air. The town of Hamm, which lies easterly, receives coal smoke only from the west, while Gelsenkirchen, situated centrally, has an atmosphere constantly charged with smoke.

TABLE XIII.

Death Rate per 10,000 during years 1900-1902.

	Hamm Pop. 32,435 30.6 NT	Glesenkirchen Pop. 37,834 57.4 NT
According to age		
0-1 years	228.9	258.9
1-5 "	57.1	131.1
5-10 "	6.5	17.3
10-15 "	1.8	2.6
15-60 "	10.7	34.7
60+ "	140.7	210.2

The influence of smoke here in raising the death rate from acute lung diseases is quite apparent. A similar cause, he believes, serves to explain the increased death rate found in the industrial regions of Westphalia and Upper Silesia, as noted in the following table:

TABLE XIV.

Death Rate per 10,000. Years 1905-1909.

Death rate from acute lung diseases in all German towns with 15,000 of a population or more	24.0
In equally large towns of Rhenish Westphalia (industrial area)	34.0
In the industrial districts of Silesia	36.0

A study of urban and industrial districts in England yielded a similar result. The average death rate from acute lung diseases for the industrial urban districts was found to be 26.5 per 10,000, and for the rural counties only 17.5.

The later studies of Ascher have disclosed a significant fact in regard to the relation of smoke to tuberculosis. He has demonstrated that tuberculous patients, both male and female, die at an earlier age than formerly. For the year 1876, of every 100 persons dying of tuberculosis in Prussia, 36.64 male and 32.64 females were over fifty years of age. Later, in 1901, only 28.20 tuberculous males and 23.54 females survived the age of fifty. Rahts has similarly shown that of every 1,000 persons of all ages dying of tuberculosis, in the city 112, and in the country 206, have passed the age of sixty. These figures would seem to justify the conclusion that with increasing industrial activity and a thickening of the population, there arises a greater deterioration of public health, not necessarily an increase in the mortality but an earlier age of death. Since the mortality from tuberculosis and other lung diseases is dependent inversely upon the resistance of the individual, the earlier age of death in industrial districts is not to be attributed to an earlier opportunity for infection, but to a lowering of the power of resistance. The factor which causes a lowering of the resistance, Ascher believes, lies in the presence of smoke from coal fires.

Again, Ascher maintains that the tuberculous lesion *per se* does not cause the death of the individual, since the tendency of such a lesion is always towards healing, a

fact readily demonstrated by pathological investigation. The fatal results are due to the secondary infection of the lungs with other micro-organisms, such as the streptococcus, pneumococcus, or influenza bacillus. Therefore, he states, "we can easily imagine that a harmful factor which increases the disposition towards acute lung diseases causes a quicker course in tuberculosis." A proof of this was seen in the influenzal epidemic in Germany in which the tuberculous patients died very quickly. From these facts, Ascher concludes that smokes causes a predisposition towards acute lung disease and hastens the course of tuberculosis.

Ascher hoped to confirm his statistical studies by means of pathological examinations of human subjects. He was unable, however, to obtain sufficient material and was obliged to forego this line of investigation. His animal experimentations were more successful. The points he sought to elucidate were:

1. Does smoke cause a disposition to acute lung disease in rabbits, *i. e.,* are rabbits which have breathed smoke for some time seized by acute lung disease, and are animals not so exposed less liable to contract such disease?

2. Does smoke cause a more rapid course in pulmonary tuberculosis, *i. e.,* do rabbits which have been innoculated with tuberculosis die more quickly if they have inhaled smoke than if they have not?

In order to investigate these questions, ten rabbits were innoculated with tubercle bacilli and these, together with ten control normal rabbits were exposed from 90 to 120 days, 10 hours daily, to a smoky atmosphere. The innoculated animals died on the average of 53.9 days, while the tuberculous control animals lived almost double the number of days, or an average of 90.3 days. In addition to tuberculosis of the lungs, other conditions which developed were bronchitis, purulent pneumonia, and peritonitis. Nor was the smoke, indeed, quite devoid of effect on the entire organism. Some of the rabbits exposed to smoke showed eczema, loss of hair, and scaling. The amount of coal dust in the lungs was small, as a rule,

except in unaffected parts where, at times, it was found in abundance. He also found that moisture combined with smoke intensified its effects. Similar, but less distinct results were obtained by causing animals to breathe soot. The same predisposition to acute lung disease and a quicker course of tuberculosis was demonstrated.

From these statistical and experimental studies, as yet the most comprehensive found in the literature dealing with the smoke evil, Ascher has drawn the following generalized conclusions:

1. The mortality of acute lung diseases is certainly increasing, especially among children and old people. The cause of this increase is due to the impurification of the air by smoke because, in the first place, the increase is greatest in industrial centers and not in agricultural districts. Since 1875, the mortality from such diseases among nursing infants has increased as much as 600%.

2. Within industrial districts a difference in mortality can also be noted, the death rate from acute lung diseases, in districts with a strong smoke development, being higher than in other industrial centers, *e. g.,* textile districts.

3. The mortality among coal miners from acute lung diseases is a much higher one (135%) than among the other male population of the same age. Here also differences can be observed in that in districts with a larger native population the mortality from acute lung diseases is a higher one than in districts where the miners have lately moved from agricultural districts.

4. The conclusion already noted, that the impurification of the air by smoke causes a predisposition to acute lung diseases and hastens the course of tuberculosis.

As was to be expected, Ascher's conclusions have elicited more or less criticism in certain quarters. Indeed, Ascher himself admits that not all doubts as to the assumption of smoke *per se* being the one factor in causing an increase in the mortality from acute lung diseases, and in hastening the course of tuberculosis, have been eradicated. It is conceivable that there may be other contrib-

uting causes which future scientific studies of the problem will be able to demonstrate.

Liefmann is an investigator who has reviewed Ascher's work and corroborated much of it. He further points out that the small industries are more culpable than the larger ones where special attention is apt to be paid to smoke consumption. He regards the supposition that smoke breathed is a menace to health as difficult to prove, and concerning the statistics of Ascher writes:

"Even though the statistical results would scarcely be in a position to give infallible proof the harmfulness of smoke, when considered along with other evidence, they have considerable weight. The high mortality from acute lung diseases among miners should cause serious reflection."

Renk is another investigator of note who would seem to regard the effects of smoke upon health as general rather than specific.

Bartel and Neumann obtained results comparable to those of Ascher in a series of animal experimentations. In experimental inhalation of tubercle bacilli by guinea pigs, these authors found that guinea pigs which had inhaled a moderate amount of smoke on account of their being kept in a large city, died from pulmonary tuberculosis in less time than those which showed smoke-free lungs.

The Sixty-sixth Annual Report of the Registrar General of England discloses the fact that there was an increase in the mortality from bronchitis and pneumonia in England during the quinquennium 1891-1895, and a considerable decrease since then. In connection with this fact Chubb has observed that eighty cities, London, Manchester, Liverpool, *et al.*, have reported a decrease in smoke since that time.

Very few observers have attempted to explain the manner in which air polluted by smoke and dust acts injuriously upon the body tissues. Bachman is one of the few who has offered an explanation. He believes that the blood of people living in cities with vitiated air becomes

impoverished, resulting in an anaemia (or better, dysaemia). This, he states, is apparent in the skin of the city dweller. The effect is not due to a local action upon the skin, but to an admixture of such air in the blood of the lung capillaries. The presence of carbon dioxide, sulphuric acid, etc., in the air inspired acts as a protoplasmic poison interfering with cellular activity and causing an inhibitory action on the ciliated cells of the respiratory tract. When the function of these ciliated cells is interfered with, only coughing and hawking can clear the bronchial tubes so as not to plug up the bronchioles. The organism has, he states, a further protection in the lymphatics and leucocytes, but eventually these auxiliary aids are insufficient to cleanse the air and the whole lymph system becomes flooded with the taking up of poisons. The lymphatic glands constitute the third protection against the dust particles. In this condition of chronic impurity of the blood, the organism suffers and is rendered predisposed to infection with pathogenic germs. The author believes that arteriosclerosis may result from this chronic poisoning. "By breathing impure air we render the body fluids impure, and this leaves the body more prone to disease."

(B) THE EFFECT OF THE INDIVIDUAL CONSTITUENTS OF SMOKE UPON HEALTH.

Smoke is composed of solid carbon particles, or soot, and certain volatile gases such as carbon dioxide, sulphur dioxide, sulphuric acid, and other compounds. We shall consider seriatim the more important of these.

SOOT.

In the literature, this term is employed with more or less latitude, at times more broadly as synonymous with coal dust, and at other times as referring simply to carbon particles. Concerning the nature of soot, Cohen defines it as consisting mainly of tar and mineral matter ash, to-

gether with small quantities of sulphur and nitrogen compounds, and frequently possessing an acid character. Various analyses show considerable variation in its composition. Soot is a product of incomplete combustion, and domestic soot, as compared with boiler soot, is said to be richer in carbon and the volatile products such as tar, ammonium chloride, and sulphate, and poor in ash. Russell, of London, first observed that soot contains sulphuric acid, the quantity, as estimated by Cohen, varying from 0.28-1.62%. According to Ascher, soot contains about 31% of mineral particles, principally silicates and iron.

The question of the fate of the inhaled carbon particle has been one that has evoked much discussion. It has been generally believed that it may enter the lung either by inhalation or by absorption from the intestinal tract and the lymphatic system. Since Villaret in 1862 suggested the probability of an intestinal origin of pulmonary anthracosis, many investigations to establish or disprove his claim have been made. His assertion that soot gets into the blood stream through the intestines has not been corroborated. As a result of a series of experiments, Arnold admits the presence of carbon particles in the interior of the intestinal tract, but never in the intestinal wall or in the lymph vessels and mesenteric glands, except in isolated instances, where barely a few pigmented cells could be seen in the intestinal tissue and in the mesenteric glands. Aschoff, Schulze, Cohen and Beitzke, in experimenting with China ink introduced into the abdominal cavity, found that this was absorbed by the lymph ducts of the mesenteric glands and of the diaphragm, the thoracic duct, the vena mammaria interna, and the blood. Thence they found it entered the bone marrow, the spleen and the liver, but not the lungs. The evidence of these authors would appear to prove that anthracosis of the lungs is caused directly by inhalation. Calmette, Guerin, von Behring and others, from experimental data, believe that particles absorbed in the intestinal tract may be carried by the lymphatics to the lungs. Oliver inclines to the latter view as a possibility "but that on this account the

intestinal canal should be regarded as the mode by which the insoluble dust more frequently reaches the lungs, rather than by direct inhalation, I am not prepared to admit. The engagement of the lymphatics in the deeper structure of the bronchi and around the blood vessels suggests the possibility of an intestinal source of infection, but the changes observed in the alveoli of the lungs in the early stages of anthracosis points to the irritation of the epithelial lining by direct contact with dust."

Oliver further points out the danger from continual exposure to dust as a factor in producing structural changes in the lungs, such as the replacement of the normal spongy tissue by fibro-connective tissue. He regards pulmonary fibrosis in the early stages as due solely to the irritation by dust. Von Behring believes that pulmonary tuberculosis in such fibrosed lungs frequently develops from the lighting up of disease long latent in the lymphatic glands as a result of a probable intestinal infection contracted during childhood. Oliver cautions persons who are employed in dusty occupations and to whom, as a result of exposure to dust, the ciliated epithelial cells of the trachea are lost, carefully to rinse their nostrils with warm water before leaving the factory.

The manner in which the carbon particles penetrate into the lung tissue after being inhaled is another mooted question. The earlier observers believed that the individual coal particles, because of their inherent hardness and angularity, bored into the tissue, while a later view is that the dust particles are drawn into the tissue by the migrating dust cells. Knauff believes that the dust penetrates the tissue both free and attached to cells. Ruppert maintains that the greater part of the dust enters the tissues without being attached to cells, since he found no evidence of inflammation around pigmented areas. He does not regard it as probable that coal, in the form of soot particles, has the physical strength for boring into the tissues, although this might be a possibility for other forms of dust.

Ruppert conducted a number of animal experiments in the Polytechnic Institute, Heidelberg, upon dogs and rabbits for the purpose of elucidating the following points:

1. What changes are caused by the inhalation of the dust in the epithelium of the air passages in the deeper tissues of the organ of respiration?
2. How does the dust penetrate into the tissue, in a free state or enclosed in cells?
3. What passage does it use in entering?
4. What forces impel it forward in the process?

From the results of his experiments he writes: "So little injurious was the soot to the respiratory organs of the animal that even weak animals can be exposed to the smoke for weeks without suffering particularly." In order to force a sufficient amount of soot into the respiratory passages, he was obliged to tracheotomize the animals. He believes that when dry coal dust is in the form of soot it is less irritating than other forms of dust, *e. g.,* stone dust. When, however, it is suspended in a fluid, as in the experiments of Slavjansky, it has an important irritating effect. The latter found severe acute pneumonia in many cases, but such changes rarely occur except when large quantities of dust have been inhaled. From Ruppert's experiments the conclusion may be drawn that soot is less harmful in its effects on the respiratory organs than the various forms of mineral dust.

Other writers express a similar opinion, that soot, *per se,* is not especially harmful, and the fact would seem to be fully well substantiated that non-carbonaceous dust (mineral and other) is more serious in its effects upon health than is carbonaceous. Sir James Crichton Brown states "that of all mineral dust carbonaceous dust seems to be the least injurious to the human organism. * * * Besides being in some degree antiseptic, carbon dust is less irritating and scarifying than many other industrial dusts, and it is really by their irritating and scarifying power that the lethal effects of dusts are to be measured." Dr. Evans of Chicago writes: "Smoke carbon is probably as little harmful as any solid which can be taken into

the human body. It is quite inert chemically. Physically, it irritates but little. The harm that it does is that it transports bacteria and secures entrance for them where alone they would be repulsed."

The question as to whether soot and coal dust possess active antiseptic properties has long been a subject for dispute. Formerly, soot and coal dust were believed to have an inhibitive action on the growth of the tubercle bacillus and tuberculous lesions. An evidence of this belief is found in the fact, cited by Jacobi, that the metal grinders of Sheffield had, until twenty-five years ago, the habit of going into places filled with coal dust after having been in the metal dust all day. The majority of such artisans contracted "Grinder's Asthma," which at present is regarded as tuberculous. This belief in the protective power of soot is now known to be largely erroneous, and Mendelssohn, as early as 1885, stated that he had met many persons dying from tuberculosis whose symptoms never showed themselves until they worked in coal dust and smoke.

Oliver thinks that soot acts in a manner different from coal dust. "Soot," he states, "increases the action of incipient tuberculosis, whereas coal dust has an unfavorable effect on the tubercle bacilli. Soot has only a mild action in preventing infection by tuberculosis, whereas coal dust is active in its immunizing qualities. The acid elements of the soot are not only an irritant, but an aid to tuberculous development. * * * It is a common experience that the course of pulmonary tuberculosis is hastened by living in a smoky atmosphere. Also that smoke predisposes to acute lung diseases. Soot differs from coal dust in being a spongy material capable of absorbing sulphuric acid and hydrochloric acid up to 10%, besides retaining other free acid gases and certain oxidation products of a tar-like nature."

According to Lehman (cited by Oliver), the sulphur-dioxide contained in soot is absorbed by the nasal mucous membrane and the particles of carbon are carried further into the respiratory passages, and are finally deposited in

the lung tissue, having meanwhile in their descent given up to the bronchial mucous membrane and the lining membrane of the lungs some of the acids which they retained.

Cornet, by means of animal experimentation, demonstrated that soot did not contain any qualities which would stop or inhibit the tuberculous process.

A number of pathological conditions in the respiratory organs have been attributed to the deposit of soot and coal dust in the lungs by different observers. True it is, that the burden of opinion, until recent years, has been that anthracosis was a condition productive of no specific phenomena of disease, and that lung lesions were independent of the inhalation of dust, and further, that coal miners were almost always immune to tuberculosis. Of late, these older views have been questioned. One condition that has been ascribed by Seltmann and others to a deposit of coal dust in the lung is that of dyspnoea. As quoted by Schlockow: "Seltmann came to the conclusion that a deposit of coal in the lungs, as soon as it reaches a certain degree, diminishes the gaseous exchange by decreasing the breathing surface, checks the formation of blood, and so causes anaemia and dyspnoea." Croque similarly attributes the dyspnoea of miners to anaemia which he regards as due to the faulty aeration of the blood in the lung capillaries around which the deposits of coal press upon the vessels so as to interfere with the flow of blood. He offers no explanation of the fact that many cases of anthracosis are not accompanied by dyspnoea.

Chronic bronchitis and emphysema are two further associated conditions towards which the inhalation of coal dust and soot is believed to exert a predisposing influence. The frequency of chronic bronchitis among coal miners is a well-known fact. Hirst believes that the inhaled particles of coal dust clog the bronchial secretions. Tobold states that the carbon itself of smoke is deposited in the nose, throat and bronchi in a fine form which acts as an irritant causing morning cough. The ciliated cells are no longer able to cope with the deposit of carbon and a chronic inflammatory condition of the mucous membrane

results. It is commonly observed clinically that emphysema follows in the train of chronic bronchitis. Merkel explains this as due to the fact that during spasms of coughing the glottis becomes compressed and the air is forced through the lower bronchi, causing distention of the alveoli and ultimately of the thorax as a whole.

Schlockow regards the dust in the air of mines as especially well adapted to produce emphysema, since certain parts of the lung tissue, due to the deposit of coal dust, are thrown out of function either temporarily or permanently. This entails increased function in the remainder of the lung tissue and, as a result, an abnormal distension of the pulmonary alveoli. Ultimately, as this phenomenon is repeated, the pulmonary vesicles lose their elasticity and become permanently distended. Racine asserts that coal dust may cause emphysema directly through this excessive inspiratory distension without the initial factor of chronic bronchitis. Every inspiration of dust laden air entering the aveoli tends to obstruct them. Each following inhalation introduces more air which, on account of these partly occluded alveoli, must find other air space. Gradually, the open air cells have an increased function thrust upon them and permanent distension results. As a proof of his view, he cites the case of two healthy young miners in whom dyspnoea developed, due to their using lamps producing an unusual amount of soot. After leaving the mine, the dyspnoea gradually disappeared but within a year in each of the miners emphysema developed without the presence of any previous bronchitis.

Concerning the incidence of chronic bronchitis and emphysema among the miners in his district, Racine has compiled the following tables:

TABLE XV.

Among a total of 870 miners there were the following reports of illness for the years 1880-1882:

	1880	1881	1882
From all causes	221, or 27.8%	242, or 29.8%	273, or 27.1%
Chronic Bronchitis	16, or 7.2%	15, or 6.2%	18, or 6.5%
Emphysema	18, or 8.1%	19, or 7.9%	23, or 8.5%

The average for these years was

For Chronic Bronchitis	6.6%
For Emphysema	8.1%

The deposit of coal dust in the lung tissue has been regarded as the exciting factor in the causation of pleurisy. The occurrence of a dry fibrinous pleurisy is frequent among coal miners. Racine, along with Merkel, believes that this may be due to a rather large deposit of coal dust in the neighborhood of the lung periphery, acting as an irritant.

A more remote injury to lung tissue dependent upon the presence of coal dust in the lungs, as observed by Seltmann and Eulenberg, is the production of small cavities, following a localized pneumonia or a limited gangrenous process within the lung tissue. They found that such areas presented the appearance of an inky fluid and at times contained pus. Racine believes that the limited necrosis is due to the pressure exerted by the deposit of large amounts of coal dust, exciting inflammatory changes which result in the formation of abscesses and cavities.

Regarding the disputed question of the inhibitive action of soot against a tuberculous process in the lungs, Racine's views are somewhat at variance with those of Ascher. He states: "My own observation leads me to ascribe to anthracosis of the lungs a protective influence against tuberculosis." He believes that soot has consid-

erable disinfecting power, and that its presence is deterrent against the growth of bacteria.

Coullard has made an exhaustive study of the effect of smoke upon the health of firemen, and his observations are of interest in their bearing upon the problem of industrial smoke and health. He describes the following symptoms arising from the inhalation of soot:

1. Effect upon the eyes. Redness and congestion of the conjunctiva, accompanied by copious tears and a sensation of prickling, as of a foreign body in the eye. In cases of severe irritation, the ciliary glands, and the lachrymal glands also, may be inflamed; or still more serious ailments (including a hypersecretion).
2. Effect upon the nasal passages. The carbon particles or heavy vapors, inhaled through the nose, cause a rapid inflammation of the nasal mucous membrane. This congestion is accompanied by hypersecretion and is frequently complicated with the frontal sinus. This inflammation is the frequent cause of frontal headaches.
3. Effect upon the pharynx. Very frequently in firemen, enlargement of the tonsils is found, which Dr. Henning of Leipzig does not hesitate to attribute to the irritating effect of smoke. Redness and congestion of the pharynx are very frequent.
4. Effect upon the respiratory organs. Irritating smoke causes inflammation of the larynx which may even develop into oedema, or swelling of the glottis, the irritation being most often betrayed by a dry, spasmodic, and very painful cough. The vapors and particles of smoke penetrate into the trachea and the bronchial passages, and in individuals subject to emphysema, or cough, bring on asthmatic symptoms. In extreme cases, bronchial pneumonia and lobar pneumonia may result, but most often pneumonia, in the case of firemen,

is attributable to the cold caused by the great quantities of water poured upon the fire.

This author further employed animal experimentation in pursuing his study concerning the effect of smoke. From the results of his experiments he concludes that the carbon particles play a large role in the production of serious symptoms. He believes that a certain number of slight disorders, frequently observed in firemen, are due to the action of carbon particles upon the mucous membranes, but he states "although it is true that animals poisoned by filtered smoke (*e. g.*, smoke from which soot has been withdrawn by filtering) return to life more easily than those which have been subjected to common smoke," he yet maintains that the poisonous gases of the smoke are responsible for the grave symptoms produced by the inhalation of smoke among firemen, rather than the soot.

Apart from its more obvious effect upon the respiratory organs, soot has for many years been more or less fancifully believed to create a predisposition towards the production of cancerous growths among workmen who are brought into contact with it. Only recently Sir Thomas Oliver has again called attention to this possible relationship. While the handling of coal itself is not apparently attended by any risk from cancer, there is some evidence for the belief that working with soot does seem to predispose towards it. To quote from Oliver: "In Great Britain we are familiar with chimney sweeps' cancer. Something, therefore, is present in soot in a chemically active form which irritates the skin and leads to cancer. That the scrotal cancer of chimney sweeps is the result of irritation caused by soot is confirmed by the youthful age and occupation of its victims. Years ago, Earl published notes of three cases of cancer occurring on the hands of gardeners, who had been distributing soot among plants. All the men were under the age of thirty. Earl's father described a case of cancer of the scrotum in a boy eight years of age who was a chimney sweep, and Sir James Paget observed the disease in the ears of workmen who had carried sacks of soot on their shoulders. Mortality

figures show that in England and Wales cancer among chimney sweeps is twice as frequent as in occupied males generally. The comparative mortality figures for cancer among chimney sweeps between the ages of twenty-six and sixty-five was, for the three years ending 1903, 133, as compared with 63 for occupied males at the same ages. We must therefore admit that the chimney sweeps' occupation is a cause of cancer." It is scarcely conceivable that the amount of soot in the air of industrial towns is sufficient in amount to be an exciting cause of cancer, as it may possibly be in the case of the chimney sweep.

EFFECTS OF THE GASEOUS CONSTITUENTS OF SMOKE UPON HEALTH.

The gaseous components of smoke, which are believed to exert a baneful influence upon health, include carbon monoxide, carbon dioxide, certain sulphur and arsenic compounds, and nitrous and chloric vapors.

Carbon Monoxide.

Carbon monoxide is a product of combustion, which is known physiologically to act as a poison on the human organism if inhaled in sufficiently large amounts. According to Gruber, an atmosphere becomes dangerous when it contains 0.05% of carbon monoxide, while Haldane believes that symptoms may be caused by as small an amount as 0.02%. Kinnicut and Sanford state that air containing 0.3% of the gas causes death, 0.2% very dangerous symptoms, and that mice will quickly show the effects of the gas when the air contains only 0.005%. The smoke from iron furnaces, it is stated, may contain as much as 25%-35% of carbon monoxide gas. When present in lethal proportions the principal symptoms produced are severe headache, vertigo, a vague feeling of illness, marked muscular weakness, and frequently nausea and vomiting. If the amount of gas be greater, drowsiness and loss of consciousness and death may result.

Gautier made an analysis of air taken from the open street and found that only 1 part in 500,000 of carbon monoxide, a proportion presumably inert in regard to health. He believed, however, that the air near factories would contain a sufficient amount of this gas to prove a menace to health. Very few estimations of the amount of carbon monoxide in the air of industrial towns have been made.

Fodor, from the results of animal experimentation, concludes that human beings are much more sensitive to the effects of this gas than are the lower animals. "If present," he states, "in greater quantities than 0.15% it is dangerous to health, especially if breathed continually, and when present in quantities of 0.05%, or even perhaps as low as 0.023%, it produces a bad effect." One of the results of long continued breathing of carbon monoxide is the production of a severe anaemia. So violent, he writes, is the action of carbon monoxide that even when an animal has recovered consciousness, after poisoning by carbon monoxide, the danger is not passed; the animal, and likewise the human being, may pay the penalty with his life, although the inhalation of carbon monoxide has ceased. The affinity of carbon monoxide for the blood, or conversely, of blood for carbon monoxide, is such that carbon monoxide is taken into the organism and into the blood circulation when the atmosphere contains no more than .004% or 1/25,000 part." For the reason that such minute amounts are harmful, Fodor does not believe that any minimal quantity is permissible in the air, and he maintains that to be perfectly healthy an atmosphere should contain no trace of carbon monoxide.

Tobold believes that, while the amount of carbon monoxide in our dwellings is not appreciable ordinarily, small quantities of it may cause headache and indisposition. Sambere regards the determining factor of the effect upon the human organism as the proportion of carbon monoxide to the oxygen breathed, rather than the absolute amount of carbon monoxide.

Coullard states that the effects of carbon monoxide and carbon dioxide inhalation by firemen are not, as a rule, very serious. The symptoms produced in firemen are mainly headache, weakness, nausea, and vomiting, fainting, dyspnoea, and a rapid pulse, coldness of the extremities, profuse perspiration with pallor of the face, diarrhoea, neurasthenia, and the development of tuberculous lesions. Practical trials prove that a robust man, entering a smoky atmosphere which contains 1%-1.5% of carbon monoxide, is affected by asphyxial disorders only very slightly serious if he does not remain in this atmosphere more than ten or fifteen minutes. For carbon monoxide to produce very rapid effects, Coullard estimates the gaseous mixture inhaled must contain at least 15% of it—ten times as much as is contained in ordinary smoke.

Carbon Dioxide.

According to Renk, normal air contains about .03% and city air about .03%-.05% of carbon dioxide. The air of factories, during the daytime, has about an average of 10.1 volumes per 10,000 of the gas, while at night, when the gas is burning, it has been estimated that there are about 17.6 volumes per 10,000. In an atmosphere in which oxygen has been reduced to 1.5% or 3%, a proportion of 12%-15% of carbon dioxide produces fatal results.

Schaffer states that in London 100,000 tons of carbon dioxide are poured into the air each day as smoke. Every ton of completely burned coal gives rise to about three tons of carbon dioxide and monoxide. According to Tobold, carbon dioxide in a proportion of 1:10 acts as a poison, causing headache and shortness of breath, while if present in a proportion of 30%, death may result. Evans believes that we can stand a much higher percentage of carbon dioxide than is ever found in the outside air, and that while carbon monoxide is directly toxic, carbon dioxide is only depressant and remotely toxic and is never fatal in "one whiff in any concentration." But, as he wisely adds, "neither does a child get a complete education in five minutes in a grammar school."

Coullard studied the poisonous effects of carbon dioxide in observing the effect of smoke on firemen. He states that a smoky atmosphere is sometimes extremely poisonous, due to the presence of quite large quantities of carbon dioxide rather than to a deficincy of oxygen. The fact that Pettenkofer was able to pass several hours in an atmosphere containing 1% of carbon dioxide without being made ill by it lead Coullard to regard this gas as not especially poisonous. Another observer breathed without difficulty for ten minutes an atmosphere in which there was 4% of carbon dioxide.

The effect of carbon dioxide inhalation may be explained as follows, according to Bert (cited by Coullard): "From the accumulation of carbon dioxide in the blood there results a progressive abatement of the oxidation within the organs, and from this as a consequence, a considerable lowering of the temperature of the body. The central nervous system in the general action upon the organism first manifests that it is affected by the loss of reflex transmission, first to the limbs, then to the eyes, then finally to the respiratory center, from which death results without any agitation or convulsive movement."

While the air of smoky towns does not contain carbon dioxide in a proportion sufficient to produce the foregoing results, nor, indeed, to prove instantly a menace to health, yet it is altogether probable, as has been suggested, that "small amounts of excess carbon dioxide, continued for long periods of time would, within limits, tend to have the effects somewhat similar to the effects of large amounts breathed for a short period of time."

SULPHUR.

The sulphur compounds found present in smoke occur mainly in the form of sulphur dioxide and sulphuric acid. The amount of sulphur, in this form in a smoky atmosphere, is at times so great that it cannot be disregarded as a probable exciting cause of ill health. It has been estimated that in London 981,792 pounds of sulphur are

poured into the air each day, or over 500,000 tons in the course of the year. In Glasgow and Manchester, it is stated, twenty tons escape each day in the smoke. According to Rideal, the quantity of sulphur found present in the air of London, from different analyses, is from 0.015-0.77 grams per 100 cubic feet. At Kew, as much as 2% of sulphur was found in an analysis of dust from an exposed surface. According to Nicholson, one-half cwt. of sulphuric acid is deposited over every square mile of Manchester, and in Chelsea very much greater deposits.

There is much unanimity of opinion regarding the deleterious influence of the sulphurous gases upon health. Concerning the action of sulphur dioxide on the human organism, Cushny states that 5 parts in 10,000 acts as an irritant causing sneezing, coughing, and lachrymation, and that, in somewhat greater concentration, it becomes entirely irrespirable; still smaller quantities in the air cause bronchial irritation and catarrh when inhaled for some time. Lehman believes that sulphur dioxide in amounts as small as .001% (0.1% being fatal) causes discomfort, and that 3 parts in 100,000 renders some persons decidedly ill after a few minutes. It is the opinion of Harrington that sulphur dioxide affects the digestive tract rather than the respiratory organs.

According to a theory expressed by Markel, sulphur is possessed of a somewhat ferment-like action in the air in its tendency to automatic renewal. This author states that sulphurous acid coming into contact with iron is immediately oxidized into sulphuric acid which, in turn, reacts upon iron forming ferrous sulphate and iron oxide. The latter drops off as rust and begins a new sulphur cycle. It is also commonly known that sulphur dioxide possesses certain disinfectant properties, being germicidal in the proportion of not less than 92 grams of sulphur per cubic metre. The presence of moisture enhances this disinfecting action and at the same time, it is believed, increases the injurious effect of sulphur dioxide upon the human organism.

It is probable that sulphurous fumes are the most deadly of all the gaseous constituents of smoke. In this connection Evans states: "Sulphur compounds are very objectionable and probably more harmful than carbon compounds. Probably before long our dense smoke ordinances will be changed so as to add to the carbon control other provisions which will control sulphur compounds. Possibly, also, the combustion experiments will likewise be directed more to the solution of the sulphur problem."

Coullard's studies among firemen did not lead him to regard the inhalation of sulphurous acid fumes as productive of any very serious disorders. Opposed to this, is the opinion of Schaefer, who has made a special study of the effects of sulphur gases on health, and who attributes lasting and serious results due to the inhalation of these gases. Sulphur fumes, he believes, play a large role in the etiology of asthma. To quote him: "The importance of sulphur dioxide as an impurity of the air of our cities and its injurious effects upon the organs of respiration is a subject that has not reached the attention, in works on hygiene, that it demands. The writer has been studying the noxious effects of sulphur dioxide as an impurity of the atmosphere for the past ten years, and he has arrived at the conclusion that it is one of the most potent causal factors of asthma."

Ascher has cited experimental work done by Kimball on rabbits which demonstrated the fact that, by causing rabbits to breathe small quantities of sulphuric acid fumes, tuberculous infections were increased. The same author states that other experimental work has shown that sulphur inhalation causes a decrease in the bactericidal action in tuberculous lungs and a lowering of the power of resistance.

Arsenic.

It has been found that most varieties of coal contain small quantities of arsenic, probably in the form of arsenical pyrites. Cohen and Ruston believe that the

arsenic which is found present in the air and water comes from the smuts of coal smoke. Traces of arsenic have been found in household dust (0.010%—0.004%) and an analysis of rain water in London showed 0.003 parts per million of arsenic.

According to Delepine, "the large amount of arsenic in soot causes a marked arsenical contamination of the air in Manchester and may account for the bad effects of air on vegetation." In regard to the effect upon health, he writes: "I have a suspicion that soot from towns where arsenical coal is used is far more irritating to the lungs than pure coal dust. The reason why I say so is that I have noticed there is generally more fibrous tissue produced in the lung in town anthracosis than when the coal is inhaled as dust, for instance in the case of coal miners. Lungs of coal miners may be as black as soot without very distinct evidence of inflammatory reaction whilst, on the contrary, in towns, where the amount of carbon collected in the lungs is smaller, there are frequently capsules of fibrous tissue in the lungs around small masses of carbon which have accumulated, indicating some irritating action on the part of soot. All town dust, as well as town air, is never free from arsenic."

In connection with the influence of arsenic inhalation upon health, Cushny's statement concerning the miners of Reichenstein, who are constantly exposed to arsenic owing to its being contained in large quantities in the ore, is of interest. Concerning these, he writes: "'These people are described by Geyer as shortlived, very subject in childhood to severe rickets and in adult life to dropsies and respiratory diseases; they offer little resistance to microbial infection and frequently present the skin and nervous symptoms of arsenic poisoning."

Nitrogen and Chlorine Gases.

These gases occur mainly in the smoke of industrial centers, especially in the fumes from factories using nitrate of mercury and from chemical works where sul-

phuric acid is manufactured. They probably play a minor role in the effect of smoke upon health. Coullard has called attention to the manner in which they appear to act injuriously. The nitrous vapors act, he states, (1) by powerfully irritating the bronchi and the small pulmonary vessels to the point of producing centers of apoplexy, and (2) by producing a special impairing of the blood." The chlorine fumes, he believes, while slightly irritating, do not cause serious disorders except through prolonged inhalation, in which case it is not uncommon for a tuberculous process to become lighted up.

As a general resume of the effects of the various constituents of smoke upon health, the following note of Mehrsten's is clarifying. This author writes: "It is not even the dust only that is injurious, but it is the invisible products of combustion escaping from the chimney in the form of gases, of which we need to take into consideration only carbonic acid, nitrogen, carbonic oxide, and sulphurous acid. The first two, which are heavy gases, can probably be regarded as injurious only when they are driven directly into dwellings and this cannot happen unless the chimneys are not high enough. The carbonic oxide, which is extremely poisonous, is usually present in such slight quantities that it becomes greatly diffused as soon as it escapes from the chimney. On account of its lightness it also arises rapidly and is lost in the higher strata of air; but, on the other hand, the gaseous sulphuric acid (sulphur dioxide) generated from the sulphur contained in the coal, which is considerably heavier than the air, is such an injurious gas that first of all our efforts must be directed toward preventing it from doing harm, all the more as it is not only the human organism that is injured but also, in a positively destructive manner, the vegetation, soil, and buildings. These facts show that any smokeless furnace with a direct combustion has little value for the public as far as the purification of the air is concerned unless the dust and the sulphurous acid are retained at the same time."

INDIRECT EFFECTS OF A SMOKY ATMOSPHERE UPON THE HEALTH OF THE COMMUNITY.

FOGS.

It is a fact long well known that a smoky atmosphere predisposes towards fogs. When an atmosphere laden with suspended particles becomes charged with moisture a fog is precipitated. According to Nicholson, over 25% of the fogs are caused by smoke.

Not infrequently, following a fog period, there is a sharp rise in the death rate of a community, the rise being due mainly to the great increase in deaths from diseases of the respiratory organs. Scientific observers of vital statistics have here once again placed varying interpretations upon this increase, a few authorities regarding the increased mortality as dependent upon the alterations in the temperature and other factors, while others maintain that the fog, *per se,* is the exciting cause of the increase. Among the former class of conservative writers is W. J. Russell of London, who, in commenting upon the effects of London fogs, writes: "By far the greater number of fogs occur when there is a great fall in temperature, and clearly this is followed closely after a few days by a great increase in the death rate; but how much of this is to be attributed to the fog and how much to the fall in temperature may be difficult to determine, but we have evidence that when fogs occur without fall of temperature they do not appear to be followed by any remarkable increase of the death rate, for on December 15, 1889, there was a dense fog and the temperature was even above the average; under the conditions, the death rate remained far above the average. On December 13 and 14 of the same year there was a dense fog, an average temperature, and only an average death rate; and the same thing happened on February 4, 1890, when, notwithstanding a dense fog, the death rate remained low, and last winter on November 13 and 14 there was a dense fog, a high temperature, and an

average death rate. With these four exceptions, depression of temperature goes with fog. There is no case of depression of temperature not followed by increase of death rate. That many people suffer, both physically and mentally, from the effects of fog there can be no doubt, but so far as I can interpret these returns of the Registrar General, they do not confirm the popular impression that fog is a deadly scourge; at the same time, it is beyond doubt that an atmosphere charged with soot dust and empyreumatic products is an unwholesome atmosphere to breathe; but I think that the principal cause of the great increase of deaths when fogs occur is attributable rather to the sudden fall of temperature than to the fog itself. As to bacteria—the experiments of Dr. Percy Frankland show that fogs do not tend to concentrate or nurture them, for he found that there were remarkably few bacteria in London air during a time of fog."

In the opinion of Rollo Russell, while cold is doubtless a contributing factor in raising the mortality during a fog period, the most potent cause lies in the smoke constituents of the foggy atmosphere. He writes: "Great cold combined with fog is not productive of much illness in the country. In smoky towns, the case is far different. Thus, in London, the death rate was raised in a single fortnight, from January 24 to February 7, 1880, from 27.1 to 48.1 per thousand. The fatality and prevalence of respiratory diseases were enormously increased. The excess of deaths over the average in the three weeks ending February 14 was 2,994, and in the week ending February 7 the deaths from whooping cough were unprecedently numerous, 248, and those from bronchitis numbered 1,223. At least 30,000 persons must have been ill from the combined effects of smoky fog and cold. * * * The large excess of carbon dioxide, sulphurous acid, and of micro-organisms and effete organic products was partly concerned in these ill effects, but the factor of greatest importance was the finely divided and thickly distributed carbon, or carbonaceous matter, which irritated the breathing passages and lungs. The results corresponded rather

closely with the gradual ill effects of the dusty trades. * * * After a fortnight of dense fogs, the deaths in London for one week ending January 2, 1892, exceeded by 1,484 the average number, being at the rate of 42 per thousand. Increases took place in the following diseases: Measles, 114%; whooping cough, 173%; phthisis, 42%; old age, 36%; apoplexy, 58%; diseases of the circulatory system, 106%; bronchitis, 170%; pneumonia, 111%; other respiratory diseases, 135%; accidents, 103%. These results are in the main attributable to the concentration of the ordinary London air with moisture and intense cold to help their deadly work. The majority of the fatal cases were weakened constitutions, though many were among the robust. The experience of large towns is that the power of recovery after illness is less within their confines than in the country. In fog, the evil influences of town air are many times multiplied." The same writer, in another place, contrasts the influence on health of a country and a London fog by quoting statistics of the death rates of Croyden and London during the great fogs of 1880. In Croyden, the number of deaths rose from 35-36 in three weeks, while in London the number rose 2,994 above the average during that time.

Ascher attributes the baneful influence of fog to the fact that the fog concentrates great quantities of smoke which is inhaled into the lungs in much larger quantities from the damp air of foggy weather than from dry air. This, he claims, has been proven experimentally. Moreover, he studied the mortality tables of Manchester in relation to fog, and drew the following conclusions: "We see that the mortality from respiratory diseases and phthisis increases during a period of fog, while the incidence of contagious diseases is not affected by it, a fact that has been known in England a long time." He was of the opinion, however, that it would not be justifiable to draw an unqualified conclusion regarding the influence of fog since other attendant conditions might also increase the mortality from lung diseases, e. g., the sudden fall in temperature, which usually precedes a fog.

Des Voeux studied the effects of two fog periods in Glasgow upon the subsequent death rate. In the autumn of 1909 there occurred two periods of smoke fog in that city, each of several days' duration but separated by an interval of a few weeks. The death rate rose suddenly during the first period from 18 to 25 per thousand, and during the second week to 33 per thousand, while the death rate in the rural environments of the city was increased only very slightly. It was estimated that 1,063 deaths could be attributed to the foggy weather.

Niven has made a similar study concerning the influence of fog periods upon the death rate in Manchester. He found that when fog periods were charted out and the number of deaths from phthisis and other forms of respiratory diseases tabulated, an unmistakable rise in death rate could be demonstrated occurring within a few days from the onset of the fog. He believes that an increase of micro-organisms occurs during fogs and that thereby a diffusion of bronchitis and other diseases finding entrance to the lungs is facilitated by fogs. The following tables showing the bearing of fogs upon the death rate are taken from his report.

Table I. Showing deaths from phthisis in each six weeks preceding, and in each of six weeks containing or following a fog, for the twenty years 1891-1910, added, the fogs not being of longer duration than six days.

Weeks preceding fogs:

6th	5th	4th	3d	2d	1st
2,192	2,040	2,049	2,135	2,161	2,224

Weeks of fog and following:

1st	2d	3d	4th	5th	6th
2,377	2,468	2,360	2,339	2,334	2,399

"It thus appears that there is an increase in deaths, greatest in the first three weeks but continuing into subsequent weeks. The greatest number of deaths is in the week after a fog."

Table II. Showing deaths from Pneumonia during weeks similarly disposed to fogs, in the same manner for the years 1897-1910, added.

Weeks preceding fogs:

6th	5th	4th	3d	2d	1st
1,351	1,389	1,345	1,442	1,442	1,494

Weeks of fog and following:

1st	2d	3d	4th	5th	6th
1,572	1,638	1,657	1,710	1,631	1,589

"There is here a clearly marked influence on mortality ascribed to pneumonia, greatest in the fourth week following the fog and next greatest in the third week. The effect on pneumonia is clearer than that on phthisis and ites maximum intensity is differently disposed, as if time were required for the development of the pneumococcus and the course of the disease."

Table III. Showing deaths from bronchitis during weeks similarly disposed for the years 1897-1910.

Weeks preceding fogs:

6th	5th	4th	3d	2d	1st
1,317	1,301	1,330	1,526	1,479	1,627

Weeks of fog and following:

1st	2d	3d	4th	5th	6th
1,808	1,864	1,848	1,699	1,729	1,749

"Here the maximum effect is manifested in the first three weeks following, the greatest effects being produced in the second week as in phthisis. The increment observed in the different forms of respiratory diseases before the occurrence of fog is due to the fact that the different fogs interfere from the proximity to each other. Thus,

while the effect of the individual fog is diminished, the total effect in producing an increase in mortality becomes more conspicuous. The increase in mortality from bronchitis, like the increase from phthisis, follows more closely on fog than does that from pneumonia. The processes are probably different. In the case of phthisis and bronchitis, fogs cause congestion; in the case of pneumonia, they probably light up pneumonia. When the fogs are of longer duration than six days, the numbers are comparatively small."

Table IV. Respiratory diseases, other than Phthisis, for the years 1891-1905.

Weeks preceding fogs:

6th	5th	4th	3d	2d	1st
304	312	289	355	363	389

Weeks of fog and following:

1st	2d	3d	4th	5th	6th
394	484	417	398	375	332

"No effect is observable under phthisis. The effect of fogs in producing mortality from respiratory diseases is unmistakable."

Diminution of Sunlight.

That a smoky town means diminished sunlight in the community is a fact universally conceded, even by such as may be skeptical concerning any direct influence of smoke on health. Indeed, some authorities are inclined to attribute the evil effects of smoke to this decrease in sunlight rather than to its irritating action on the organs of respiration. In this connection, Kister writes: "The development of smoke and soot has without doubt a bad effect upon the daylight and sunshine of a place, and, be-

cause of the hygienic significance of sunshine, is inimical to our physical, or at least our psychical, welfare. But it is not easy to prove such a direct injurious effect of smoke upon our respiratory organs."

The precise manner in which a diminution of sunlight acts injuriously on health is a subject more or less under dispute. It is well known that sunlight is germicidal. Tubercle bacilli quickly succumb to the action of direct sunlight, a few hours' exposure sufficing to destroy their vitality, although they may live indefinitely in darkened surroundings. Quite apart from this bactericidal action there are apparently other factors, in decreased sunlight, which militate against health. Liefman has grouped these harmful influences under three headings. "If," he states, "we group all these experiences in the significance of light for our life and health, and concentrate them upon the problem which here interests us, we shall be led, in my opinion, to the conclusion that a darkening of the atmosphere of our great cities is injurious to health in three ways: (1) An exciting impulse which influences our disposition is weakened and the energy of metabolism, especially as it concerns respiration, is diminished. (2) The illumination and warming of the earth, the water, and the air within the precincts of our great cities is diminished and in this way a series of hygienically important processes is influenced or depressed. (3) The chemical and bactericidal effect of the sun's rays is decreased and thus bacteria, especially the pathogenic ones, are permitted to thrive.

Sir William Ramsay regards smoke as harmful by virtue of its power directly to absorb light, and by its effect in the formation of clouds and fogs which, he states, are peculiarly fitted to absorb the blue, the violet, and ultra violet rays, these being the rays that are especially germicidal. In this manner a diminution of sunshine causes an increase of bacteria, both pathogenic and non-pathogenic, in the atmosphere. The same writer believes that sunlight has a direct influence on the human skin as well as upon mental states.

In order to ascertain the possible bearing of diminished sunshine on the mortality returns from respiratory diseases, Niven has compiled the following statistics for the industrial cities of Manchester, Birmingham, Sheffield and London:

RELATIVE MORTALITY FROM RESPIRATORY DISEASES AND RECORD OF SUNSHINE

	PHTHISIS				BRONCHITIS				PNEUMONIA				SUNSHINE (Hours)			
Year	Manchester	Birmingham	Sheffield	London	Manchester	Birmingham	Sheffield	London	Manchester	Birmingham	Sheffield	London	Manchester	Birmingham	Sheffield	London
1901	2.09	1.73	1.41	1.71	2.22	2.07	1.51	1.62	1.96	1.73	1.45	1.35	1192	1144		1567
1902	2.08	1.65	1.18	1.65	2.44	1.91	1.52	1.71	1.98	1.62	1.45	1.47	928	1048		1228
1903	1.85	1.45	1.36	1.62	1.87	1.73	1.71	1.15	1.87	1.48	1.58	1.28	1119	972	1216	1445
1904	1.98	1.54	1.27	1.70	1.97	2.06	1.51	1.40	2.18	1.72	1.39	1.45	1031	1239	1325	1459
1905	1.56	1.45	1.15	1.50	1.85	1.68	1.56	1.33	1.62	1.55	1.44	1.53	1005	1149	1432	1420
1906	1.71	1.29	1.05	1.53	1.74	1.68	1.46	1.18	1.59	1.47	1.32	1.45	1069	1143	1438	1735
1907	1.70	1.29	1.20	1.51	2.06	1.76	1.76	1.32	2.02	1.66	1.70	1.66	894	952	1428	1417
1908	1.65	1.39	1.28	1.44	1.96	1.73	1.65	1.15	1.75	1.35	1.59	1.46	992	981	1281	1634
1909	1.70	1.44	1.17	1.44	2.00	1.77	1.32	1.35	1.72	1.46	1.54	1.68	999	1129	1332	1641
1910	1.49	1.25	1.01	1.28	1.59	1.51	1.26	1.12	1.40	1.33	1.52	1.49	982	1011		1380

It is difficult to draw any exact conclusions from this table, the evidence presented being, on the whole, somewhat equivocal. A more or less general decrease in respiratory diseases (with the exception of a slight rise in pneumonia in London and Sheffield) may be noted but it cannot be demonstrated that this general decrease is concurrent with an increase in the number of hours of sunshine in the four cities. London and Sheffield show a slight increase in the number of hours of sunshine; Birmingham and Manchester present a continuously decreasing number of sunlight hours.

Some statistics of Kister for the city of Hamburg, one of the smokiest of German towns, are comparable with those of the English towns. The following table is taken from a report of this writer on the Investigation on Smoke and Soot in Hamburg:

MORTALITY FROM NON-TUBERCULOUS DISEASE OF THE RESPIRATORY ORGANS.

For the City of Hamburg.

(Diphtheria and Whooping Cough are not included.)

Year	Under 1 yr.	1-15 yrs.	15-30 yrs.	30-60 yrs.	60-70 yrs.	Over 70	Total	% of Dead	.01% of Living
1894	412	305	17	143	258	173	1308	12.08	21.636
1895	559	400	22	153	289	280	1703	14.50	27.513
1896	509	377	14	152	261	324	1537	14.03	24.204
1897	417	279	20	149	260	246	1371	12.37	20.996
1898	527	309	18	139	245	255	1578	13.51	23.589
1899	405	363	27	158	339	348	1630	13.74	23.807
1900	527	414	20	218	417	1318	2914	16.50	28.935
1901	548	405	19	156	328	324	1780	14.49	24.845
1902	444	293	21	169	369	342	1748	14.55	23.854
1903	390	333	33	177	364	322	1619	12.99	21.674
1904	441	310	22	155	373	313	1614	13.37	21.081
1905	422	315	51	325	265	384	1762	14.09	22.262
1906	535	358	44	296	223	322	1778	14.24	21.768
1907	466	262	62	419	280	429	1918	15.37	22.709

The comments of the author upon this table are, in part: "If we collect the figures for Hamburg, the following (the table) shows a decrease or perhaps an increase

in recent years from other diseases (non-tuberculous) of the respiratory organs. * * * Even though this fact cannot be referred, without further investigation, to the development of smoke, it is one of the phenomena that must be taken into account in the question of the hygienic effect of smoke."

OTHER REMOTE EFFECTS OF SMOKE UPON HEALTH.

The psychological aspect of the smoke nuisance has been dealt with at length in another Bulletin of this series. The present day recognition of the importance of the mental influence of mind upon bodily health is a hopeful sign of the times. It is doubtful whether the maximum of mental acumen and bodily efficiency may for long be preserved in a smoke laden atmosphere. True it is that, at times, certain minds can rise above their environments, but whether the sum total of the mental efficiency of the community can be equal to that of a community living within cleanliness, aerial and environmental, seems scarcely conceivable. Not infrequently one hears the complaint of the casual visitor to a smoky city with respect to a feeling of mental depression provoked by the smoky atmosphere. Certain physicians have pronounced themselves upon this aspect of the problem. Dr. Evans of Chicago writes: "It (smoke) serves to lower the general tone of a community. A spotless town is more apt to be moral than a dirty town. It is useless to try to get a spotless town and leave the smoke. If the air is dirty it is very hard to get the streets, the yards, the clothes, the people clean." C. A. L. Reed speaks in a similar strain: "Physical dirt is closely allied to moral dirt and both lead to degeneracy. It is too much to expect the best results in the public schools that exist beneath the sombre shade of smoke. It is difficult to imbue the young with a sense of the beautiful when the beauty itself is bedaubed with soot." Jacobi believes "that a clean community has the better chance to avoid degeneracy," and

Des Voeux asserts that "dirt and darkness are the twin children of smoke, and to them are closely related poverty, drunkenness and crime."

A further quite obvious factor which renders a smoky town unhealthy is the necessary curtailment of free house and factory ventilation. To open a window carries with it the certain penalty of soiling a curtain, a rug, or a counterpane. The zealous housewife accordingly is prone to guard the cleanliness of her house at the expense of fresh air. Out of door sleeping porches are, for a similar reason, conspicuous by their absence in smoky towns, in contrast with their increasing use in more cleanly modern cities. The fine shower of soot detracts from the comfort of sleeping in the open air and speedly soils the bed linen. Such a more or less universal avoidance of fresh air militates strongly against the health of the community and predisposes its inhabitants to tuberculous and other diseases.

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Pulmonary Arthracosis—A Community Disease

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Definite observations upon the presence and nature of pigment within the lung substance and its associated lymphatic structures are of relatively recent date. Nevertheless, as early as 1717, Ramazzini discussed the presence of carbonaceous material within the lung and indicated an association with definite pulmonary diseases. His observations were made upon various laborers who, through the inhalation of angular stone particles, became predisposed to asthma and tuberculosis. His observations, however, did not suggest that any of the foreign material contained within the lung consisted of a carbon deposit.

Not until Pearson in 1813 studied the problem and applied the term anthracosis or coal miner's lung, followed by a report by Laennec in 1819, was a more acute attention attracted to the subject. Pearson indicated that individual coal particles when inhaled became deposited in the lung tissue and upon the accumulation of larger quantities of this pigment, the lung gave macroscopic evidence of its presence.

This contention was further supported by Gregory, who in 1831, described the pigment in the lungs of a coal miner with definite tissue changes within the organ. Other English authors (Thompson, Simpson and Stratton) made similar observations and indicated the importance of anthracotic deposits as a type of occupational disease.

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Although Pearson's views were accepted in England, they were strongly combatted in Germany, particularly by Koschlakoff, as well as by Virchow and Henele, who regarded the coloring matter in the lung substance and in the lymph nodes of haematogenous origin. Virchow did not believe that the lung substance could be penetrated by inert foreign particles. As late as 1855, Barthelmess discussed "pulmonary melanosis" as a progressive pigmentation of the lung resulting from repeated haemorrhages and inflammation. Subsequently, however, Pearson's observations were confirmed in Traube's clinic (1860) where some carbon pigment, presumably having its origin from charcoal, was demonstrated in the lung substance. Since then the deposition of carbon from smoke has been amply confirmed by studies upon human lungs as well as by animal experimentation. The first confirmatory animal experiments were carried out by Knauff (1867) and repeated by Konradi (1869).

In the earlier discussion upon the inhalation of dust, including the carbon particles of smoke, it was indicated that as every one inhaled more or less of it during his lifetime, little pathological change, other than the storage of pigment, occurred in the lung tissue. It was, however, recognized that the inhalation of different foreign substances had a varying effect upon the respiratory organs. It was deemed that carbon pigment had the least harmful effect and, hence, the deposits which were found in the adult lungs, could be disregarded as having any association with respiratory diseases or clinical symptoms during life.

With the admission that the black pigmentation of the lung was the result of the inhalation of carbon particles contained in the air, a considerable controversy began concerning the manner in which the foreign material made its entrance into the tissues. It was not uncommonly observed that the sputum of individuals working in smoky atmospheres would, for considerable periods of time, contain black pigment particles. Some of this foreign material was free, while some was contained with-

in cells. Knauff believed that these cells were desquamated epithelial structures of the bronchi, which had lost their cilia. It was thought that with the active desquamation of the epithelial lining that a more ready access for the pigment to the deeper structures was possible. Sikorsky and Klein both believed that foreign particles were able to pass between the uninjured epithelial cells and directly enter the lymphatics.

On the other hand, Arnold and Schottelius opposed the view of the direct migration of the pigment into the tissues and claimed that the transport was accomplished only through the agency of cellular activity. This phagocytosis they believed could be accomplished by the bronchial epithelium, lymphoid wandering cells and by the alveolar epithelium. Traube thought that the acicular nature of the carbon particles would account for their tendency to pierce the delicate alveolar walls and then to migrate to other parts by the lymphatic channels. Rindfleisch accepted this latter view, laid stress upon the gritty hardness of the particles and believed that through the impact of the air current the particles may be driven through the superficial tissues. He furthermore pointed out that when these foreign particles had entered the lymph spaces they not uncommonly became incorporated within cells having phagocytic properties.

The theory of the phagocytic transport of the foreign particles continued to gain ground but there was no agreement concerning the nature of the active cell. Slavjansky and Ins believed that the leucocytes were most active, while Ruppert, Schottelius, and others believed that the alveolar epithelium picked up the carbon from the air sacs. Arnold was divided in his views, considering that both types of cells were capable of carrying out this function, while, furthermore, he believed that under certain conditions migration of pigment might occur in the absence of phagocytic cells. Even to the present time, observers are not in unison concerning the taking up and storage of the pigment which reaches the lung. The exact nature of the phagocytic cells, and these seem to be the

active participants in the accumulation of carbon pigment in the pulmonary structures, is still in debate. In a recent study, however, it appears to us that Haythorn has conclusively shown that although pigment may appear in a variety of cells, the important cell acting as a carrier from the air sac to the interstitial tissue and the lymphatics of the lung, is an endothelial cell.

Although, in the early days of cellular pathology (1858) the finding of extensive pulmonary anthracosis was unusual, the situation has changed much in the present day. Then, as now, the most intense examples of pigmentation of the lung were found among the coal miners, and it was particularly to these that Pearson, just a century ago referred, when he first applied the name anthracosis to the pulmonary condition. Apparently, early in the last century, in the course of ordinary life the accumulation of pigmented dust bodies within the lung was hardly sufficient to attract the attention. At that time, the use of coal was less general among the housekeepers and the combustion of wood was relatively complete, with but slight pollution of the air. Then, too, coal was not in as general use in industries nor had the use of the steam engine found a definite place in manufacture.

To-day the use of coal forms the main source of energy for the remarkable industries, which began in the middle of the nineteenth century. We need not indicate by figures or statistics the extent to which our progress is determined by the use of coal. Nor is it within our province to indicate the enormous losses entailed in the incomplete combustion of coal. The main fact stands before us to-day that in every city where householders use coal or in which manufactures of any capacity are located, the air shows a greater or less pollution by carbon particles. To-day it is almost possible to gauge the extent of the manufactures within a city by estimating the quantity of carbon in the atmosphere. In other words, what, not so many years ago was a rather unusual aerial condition, to-day forms a constant finding and has added a nuisance which affects the well-being of the community. No longer may we re-

gard the presence of carbon in the air of large cities as a harmless factor. And furthermore, the gradual accumulation of this foreign material within the respiratory tract has a definite effect upon the tissues in reducing their functional activity and in possibly leading to secondary disturbances affecting our general bodily health.

The following observations have been made upon a series of autopsies, in which the deposit of carbon pigment within the lungs was particularly noted. These observations were made upon civilians not engaged in coal mining. The majority of them had been residents of the Pittsburgh district for the greater part of their lives. We were unable to account for the great variation, which occurred in the intensity of the pigmentation among the different individuals, particularly when their respective occupations appear to have had no relation to the amount of the pigment deposit in the lungs. Thus one of the most markedly pigmented lungs was obtained from a peddler, in whose history we could find no particular association with a sooty atmosphere or industry. It is possible that the tissues of different individuals store the foreign particles from the air with different degrees of activity.

Admitting that but few individuals to-day can escape the accumulation of carbon particles in the respiratory system, it may be suggested that the condition should be looked upon as a normal process. This attitude has been the dominant one in the discussion of pulmonary anthracosis. As, however, we must to-day freely admit that individuals living under different circumstances and in different communities suffer unequally from the quantity of inhaled dust, it is impossible for us to designate all of these as normal conditions. That a small amount of anthracosis of the lungs is not incompatible with good health is obvious to all who have observed the condition in many autopsies. That, however, certain communities are subject to greater pollution of the air by smoke than others, and that the individuals in these communities suffer in an equally greater degree from the inhalation of soot and smoke is also obvious to those who have had an oppor-

tunity of comparing the lungs from different localities. The pathologist has no difficulty in recognizing lung specimens from large manufacturing cities.

Thus we are able to observe variations from the almost non-pigmented lung tissue obtained from those living far distant from cities, to the more intensely pigmented lungs, the coal miner's lung illustrating the extreme degree of carbon deposit. There is, however, some difference between the deeply pigmented coal miner's lung and that obtained from the city dweller. The carbon dust as inhaled in the coal mines is considerably coarser than the fine particles of soot found in the city air. Moreover, the dust in coal mines is made up of fine angular and rough particles, while soot is a mixture of a very fine amorphous carbon and ash.

ANATOMICAL CONSIDERATIONS.

The deposition of carbon pigment in the lungs from the dust-laden air is dependent upon the respiratory function and the activity of the lymphatics. The inhaled air with its carbon particles is carried to varying depths into the lung tissue. The major amount of the foreign material adheres to the moist walls of the respiratory passages and never reaches the lung tissue proper. It is possible, and microscopical analysis seems to confirm this, that the foreigu material that adheres to the mucous membranes of the nose, pharynx, trachea, and larger bronchi is but rarely carried into the tissues of these tracts, bnt lying in the secreted mucous, is carried upwards and is eventually expelled. The relatively lesser quantity of dust and carbon which reaches the lung alveoli also becomes adherent to the moist surfaces of the alveolar sacs and then by the activity of certain cells which have been studied and described by Haythorn, these particles are eventually carried into the lymphatics of the alveolar wall where they are disposed of by the lymphatic system of the part. The subsequent distribution is to a great extent determined by the site of absorbtion within the lung. Thus

the carbon particles which have found their way into the air sacs near the surface of the lung, gradually accumulate within the lymphatics of the visceral pleura, while the carbon which is collected from the more centrally placed alveoli, accumulates about the lymphatic channels which drain that particular area. The tendency of this absorbed carbon is to pass from the finer lymphatic channels of the alveolar walls to the larger passages, eventually reaching a lymph node where the onward progress of the particles is impeded by the filtering action of this structure. In the main, the lymphatic drainage of the entire lung converges at the hilus and passes into the peri-bronchial glands located in this part.

The lymphatics of the visceral pleura form an intricate network of channels which surround each lobule. The lymphatics upon the pleural surface of these lobules can, at times, be recognized by the naked eye. Many anastomoses occur and the larger channels drain towards the hilus. Communications between the surface lymphatics and those within the organ have also been demonstrated.

A somewhat similar system of lymphatic channels have been demonstrated about those lobules which lie within the lung. Not only is there a system of lymphatic channels about the lobules, but small passages extend into the individual alveolar walls. Sikorsky, as well as Wittich, claimed to have demonstrated small patent communications between the lymphatic channels in the alveolar walls and the air sacs. By this means, it was suggested, that foreign materials within the air sacs could find a ready passage into the interstitial lymphatic system. In 1878 Rindfleisch suggested similar passages for the entrance of coal pigment into the lung tissues. He believed that the fine dust particles could pass directly from the air sac into the interstitial lymphatic channels without the intervention of phagocytic cells. He did appreciate the role of phagocytosis in the subsequent transportation and storage of the foreign material. It would appear, however, with the most recent studies that the migration of

the dust particles from the air sacs occurs only through the agency of certain wandering cells.

To thoroughly appreciate the progressive pigmentation of the lung substance by the inhalation of carbon particles, the general mechanism of respiration as well as the efficient lymphatic drainage of all the air sacs must be understood. The important conclusions of Beitzke and Most, that the lymphatics of the lung and visceral pleura have no direct communication with those of the head, neck, or abdomen, and the fact that carbon particles are rarely found in the circulating blood, indicate that pulmonary anthracosis is developed through the activity of the respiratory functions alone. It is, therefore, quite out of place, here to discuss the claims of Calmette, and his associates, for the origin of pulmonary anthracosis in the alimentary tract. A more extensive review and study of the relation of intestinal absorption to anthracosis is given by Montgomery. This author from his own experiments concluded that the respiratory route alone was the important one leading to pulmonary anthracosis.

DISTRIBUTION OF PIGMENT BENEATH THE VISCERAL PLEURA.

At first sight, when the lung is examined externally, the distribution of the deposit of carbon pigment seems to be irregular and without any association with the anatomical structure of the lung. The pigment is deposited in small granular masses, which, in their beginning, occupy areas less than of pin-head size. Sometimes it would appear that the deposit is in the nature of lines which, however, on slight magnification are found to be the coalescence of numerous small granular points.

As the deposit becomes more extensive, the pigment is found to follow a definite arrangement and the anatomical structures which, in the non-pigmented lung are not visible, are mapped out by the deposit. Thus the subpleural pigmentation is found to pick out the septa dividing the lobules of the lung. This geographical marking is

more particularly evident in the early stages of the pigmentation prior to the diffuse deposition of the pigment with the consequent obliteration of the early linear markings. Whereas in the early stages of the deposit, the septa of the lobules show fine linear deposits of pigment, the increasing accumulation of the carbon leads to an irregular thickness of these lines and the conversion of them into small chains of nodules or to the development of flat or shot-like masses in the sub-pleural tissues. Gradually the deposit extends from the septa into the tissues of the lobules until blotches of pigment become prominent. All gradations, from the finest hair-like lines in the septa, to diffuse pigmented areas in which the normal color of lung substances can not be recognized, are not uncommonly seen in the same lung.

The macroscopic appearance of the sub-pleural tissues is a very good gauge as to the actual amount of carbon pigment contained in the lung. That is, with the deposit of such an obvious pigment no difficulty is experienced in distinguishing its presence or in gauging the amount present in each portion of the tissue examined. It is well, however, to recognize that the amount of carbon pigment on the surface does not necessarily indicate the extent or distribution of the pigment in any part of the lung tissue. There are factors arising with each lung and within each lobe which tend to modify the amount of pigment within the tissue.

Although the pigment follows the septa of the lung lobules, the distribution upon the surface is by no means uniform. It has been repeatedly observed that the amount of pigment in the different lobes as well as in the different portions of the same lobe varies very considerably. The distribution of the pigment in the sub-pleural tissues is dependent upon the course of the lymphatic stream. But, as has been indicated by S. R. Haythorn, the presence of carbon pigment within the lung may have a marked effect upon the subsequent condition of these lymphatics. Thus, as we shall discuss later, the deposition of carbon pigment resulting through the activity of certain phagocytic cells

has a tendency to stimulate tissue changes which modify the architecture of the organ. It is most probable that by this means the deposit occurring in the lung tissue does not always appear in the same characters, but according to the particular tissue reaction (fibrosis) a modification of the lymphatic system leads to an altered physiological process in which the amount of deposit may be increased or decreased.

In the examination of a series of lungs it soon becomes evident that there are certain areas in the normal organ, which become involved earlier than others, and which usually show the most intense pigmentation in the later stages of the process. Thus in young adults, who show no evidence of other disease processes in the lung, the pigment is more prominent in the apex of the upper lobe, the anterior border of the upper lobe, and the posterior border of the upper and lower lobes. Even in these three areas the distribution of the pigment is by no means uniform, for in different individuals the grades of intensity of the deposit differ somewhat within these locations.

It is the usual observation that the least pigmented portions of the pleural surface of the lung are the diaphragmatic and the interlobar surfaces. It is not uncommon, however, to observe a sharp line of pigmentation separating the outer surfaces of the pleura from the interlobar areas. At the border of each lobe as it lies in apposition to its fellow, there is a marked pigmented zone, more intense than the deposit upon the free surface, and serving as a boundary between the pigmented pleura and the non-pigmented interlobar surfaces.

The distribution of pigment in the apex of the lung varies according to the shape of the part and to the character of the dome of the chest cavity. As has been pointed out by Schmorl it is not uncommon to have an unusual prominence of the upper ribs and irregular folds of the parietal pleura forming bands which divide the otherwise round dome of the chest cavity into several smaller compartments. These abnormal ridges are very common, but are not constant in their disposition. Not uncommonly

they pass from behind inwards and forwards, crossing the dome in an arched and rather spiral direction, the anterior extremity passing towards the hilus of the lung. At other times, folds of parietal pleura pass from behind upwards and forwards, crossing the highest points of the pleural sac. When these folds are marked a definite depression is left upon the lung surface, particularly if the lung is unduly distended by emphysema or pneumonia. This depression is observed in the nature of a groove looking not unlike the vertical grooves seen over the right lobe of the liver (Liebermeister's groove). These grooves become more marked and more permanent with the age of the individual. Not only do they present depressions in the soft and spongy tissues of the organ, which, in the early years of life, can easily be obliterated, but in the course of years they remain as definite areas of retraction where the lung substance does not expand nor develop equally with the rest of the tissue. Thus in the apical grooves the lung tissue is inhibited in its growth and its functional activity is hindered by obstructing bands. Moreover, the lung tissue opposite the depths of the grooves is prone to become fibrosed or to develop adhesions to the parietal pleura.

These apical grooves are also to be recognized in the variation of the deposit of the pigment. The grooves when well marked attract the attention by showing a lessened amount of pigment than the surrounding tissue. When several well marked grooves occupy the apex of the lung, then this part of the lobe appears to contain decidedly less pigment than other parts. Yet on closer examination, although the apical pleura may appear to contain less pigment than the other pleural areas, this is due to the absence of pigment in the grooves themselves, and not to the variation of pigment in the parenchyma of the lobe.

The ridges bounding these grooves usually show an unusual pigmentation. The extent, however, of the deposit on the borders of the grooves, is not uniform in that it is not uncommon to observe one border deeply pig-

mented while its fellow on the opposite side contains but little carbon.

The intensity of the pigmentation along the posterior border of the upper and lower lobes is commonly the most marked in the entire organ. From the early beginning of a tortoise shell marking indicating the division of the lobules, the condition progresses until the pigmentation produces one diffuse coloration of the pleural tissues.

Furthermore, there are two important considerations respecting the localization of anthracotic pigment in the pleura. The first of these is the relation of the pigment deposit to the position of the intercostal spaces and the ribs. The second is the relation of the pigment deposit to the opposed pleural surfaces between the neighboring lobes.

In respect to the relation of the pigment to the ribs and intercostal spaces there have been a number of views expressed. As above stated, our attention has been particularly attracted to this question through the observations of Schmorl upon the apical grooves of the lung. Similar rib impressions are found in adults upon the surfaces of both the upper and lower lobes. Schmorl in 1901 indicated that the uppermost ribs produced individual impressions upon the lung substance which were easily recognized at autopsy. Schmorl found these depressions in children, but noted that they tended to disappear with advancing age. He believed that the depressions were the result of the undeveloped chest pressing upon the lung substance and that with the development of the thorax, in the normal individual, the pressure upon the lung was much relieved. He noted, however, that in those individuals, whom we are prone to look upon as possessing the anatomical character of a tuberculous subject, the flat chest, these grooves or rib depressions upon the lung remained permanently. Thus he believed that the anatomical characteristics of the chest altered the relationship of the lung to the pleural cavity which in the undeveloped condition was prone to bring about those anatomical changes of the lung, inviting tuberculosis.

The grooves in the lung tissue had the effect of compressing both the lymphatic and blood vessels. Likewise a certain interference might be produced in compression of the bronchial tree. These pathological conditions tended towards a stasis of the circulation of the part, permitting a more ready development of the tuberculous process.

It has, furthermore, been shown that not only do the ribs in the uppermost portion of the thorax leave their impression on the lung tissue, but that such marks may be distinguished for the entire series of ribs down to the eight or ninth. These rib markings or impressions are more readily followed by observing the deposit of pigment than by the actual depressions produced upon the lung substance.

As one will readily appreciate, the intensity of the impressions of the ribs upon the lung varies in different individuals. Not uncommonly, the thorax is of such dimensions or its capacity bears such a relation to the lung, that little or no effect of rib pressure is to be noted. Under those conditions in which the volume and consistence of the lung is increased, as in lobar pneumonia, the rib depressions are temporarily more decidedly marked.

Peiser has studied a series of cases and finds that the rib grooves are not well marked in the infant. In this he differs from Schmorl. He believes that the rib grooves increases in their depth as the individual assumes the upright position and the thoracic wall sinks. As the thorax, with increasing age, gradually assumes its new level, the upper ribs become more prominent on the inner wall of the thorax. These then produce depressions upon the lung surface. Not only does the sinking of the thoracic wall lead to the prominence of the rib margins, but the respiratory movements are altered, there being a diminished respiratory activity established. This in its turn has the effect of producing a pulmonary stasis and a lessened elasticity of the lung. Peiser believes that with the altered condition of the respiration, the character of the lung sub-

stance changes so that the rib grooves are more readily produced.

Further observations have recently been made by Orsos. He studied the mechanics of respiration as regards the relationship of the expanding thoracic wall to the spongy lung substance within. He indicates that the thorax, constituting a closed cavity, has its walls made up of parts which are of different composition. In part, the wall consists of solid structures, the ribs, while in other places soft portions, make up a part of the active walls. He points out that the effect of these two types of tissue upon the lung substance is different. The solid ribs, he believes, are more active in producing a suction by the expanding chest and a compression by the contracting chest wall. This greater activity in relation to a part of the chest wall has its effect upon the lung substance in that the tissue immediately opposite the firm ribs is functionally more active during the respiratory movements. The inactivity of the intercostal spaces is not only to be observed in the smaller alveolar spaces, but also in the more sluggish lymphatic drainage leading to the greater deposition of the insoluble carbon particles. Thus in the adult the intercostal spaces become more richly marked by the deposit of anthracotic materials.

In discussing the views expressed by Orsos, an opposite stand was taken by Marchand, Aschoff and Beitzke, in that each of them expressed his belief that the greater deposit of pigment occurred in the areas mapped out by the ribs.

In our own observations, we must, in the main, agree with the findings of Orsos. Some difficulty is experienced in determining which portion of the lung lay opposite the ribs, particularly when there have been no marked depressions, while the deposit of pigment is quite decided. There can, however, be no doubt, as to the depressions opposite the first, second, or third rib, and in these situations, the grooves which are very decided contain less pigment than the high points of the ridges. At this point, however, it is necessary to introduce a word of explana-

tion in discussion of the pigment deposit in and about the costal grooves. It is best to study those lungs which are moderately advanced in the anthracotic process, and which are not altered by the presence of adhesions. Inflammation introduces a factor which modifies the normal distribution of pigment so that we can no longer ascribe our findings to the influence of the costal grooves alone. We shall discuss the effect of inflammation upon the deposit of coal pigment at another place.

It is, furthermore, to be indicated, that the deposit of pigment along the intercostal areas is not uniform. Although the margins of the grooves as well as the intercostal spaces contain the greater amount of the pigment while the depth of the groove is almost always free, it is impossible to make a common statement as to the exact outline of the deposit for each groove. No doubt, the intensity of the pigmentation is determined to a certain extent, by the individual characters, such as the prominence of the ribs, the corresponding depth of the groove, and the local pressure upon the lymph and blood vessels.

In support of the views of Orsos that the cavity of the grooves exhibit less pigmentation than the surrounding portions, is the fact that the natural depression as well as the opposed pleural surfaces between the lobes have the same characters as the rib grooves in being less pigmented than other parts. It is the common observation to find a pale non-pigmented pleura on the interlobar surfaces while the external visceral pleura is mottled by a pigment deposit. The same is true of the diaphragmatic surface. Here, too, a less amount of pigment accumulates. This variation in the distribution of the pigment upon the pleural surfaces is not dependent upon the difference of the respiratory function of the lung alveoli beneath these parts, nor is it due to a difference in the character of the distribution of the lymphatic channels which surround the lung alveoli, but it is dependent upon outer influences of pressure which modify the capacity both of the alveoli and lymphatics. In the normal lung these influences of pressure are to be observed mainly in the rib grooves, the

interlobar and diaphragmatic surfaces. It is possible that the presence of points of pressure upon the lung tissue has the quality of massaging the parts during respiratory activity and thus driving the particles of pigment more rapidly to other parts. We are inclined to believe that this quality of massaging the part by intermittent friction, plays the important role of preventing the accumulation of carbon pigment in the given regions of the lung. As we shall point out later, the lack of flow in the lymphatic system does not prevent the accumulation of foreign particles. Stasis of the lymphatic system, although preventing the fluid within the channels from flowing with normal rapidity has little effect upon the migration of the cellular elements, which are the main means by which the foreign material is transported. Thus, although stasis prevents the proper flow of the serum through the lymph channels it permits the wandering of phagocytes into the obstructed region where these may accumulate in undue proportion. These wandering cells with their pigment burden are the chief causes for the pigmentation of the given areas of lung tissue.

INTERSTITIAL PULMONARY ANTHRACOSIS.

The nature of the distribution of carbon pigment in relation to the pulmonary alveoli within the lung is very similar to that observed upon the pleural surface. We do not, however, have an opportunity of viewing the pigment in the same manner. Thus in a cross section of the lung we do not have the opportunity of observing the surface of the lobules, but see only cross sections of the partitions. Thus for the most part our attention is attracted to the deposition of pigment at the points where the partitions meet. In these situations we observe small nodular deposits not uncommonly the size of pin heads. At first sight, it would appear that the amount of pigment within the lung is relatively less than that observed on the surface. Nevertheless, it can be observed that the total amount of pigment within the lung tissue bears a rela-

tion to the quantity observed on the surface. In the normal lung, however, the distribution within the tissue is more uniform than the distribution of carbon in the pleura and there is not the macroscopic variation in different parts of the lobes, save at the hilus where the parenchyma is more pigmented on account of the greater accumulation in small lymphatic channels and nodes.

Furthermore, the unequal distribution of the pigment as it is observed upon the pleural surface has no direct relation to the deposition within the organ. The lack of pigment upon the interlobar surfaces and in the rib grooves is only a superficial condition and does not affect the deeper underlying lobules. The earliest deposits of coal pigment are to be looked for mainly in the perivascular lymphatics of the smaller branches of the pulmonary artery, subsequently, pigment appears in the regions of the small bronchi and venules. In all of these situations its presence becomes more marked with the increasing quantities of soot that are constantly inhaled.

As the accumulations of pigment gradually increase, they not only form lines along the septa of the lobules and the vascular channels, but nodular collections appear at the points of junction of the various lymph channels, where small receptacula are formed. These nodules becomes so prominent that they are readily felt by the finger and at times the course of the lymph channel can be detected by the feel.

Tissue changes may or may not accompany these larger depositions of pigment. In the majority of instances, however, a process of fibrosis, not accompanied by any inflammatory exudate, makes its appearance and surrounds each pigmentary nodule. These can be detected by the naked eye, while the larger ones, which are shot-like and gritty, are commonly spoken of as "anthracotic nodules."

In none of our specimens were we able to observe any uniform variation in the deposit of the anthracotic pigment within the lung of normal individuals. The greater quantity of pigment along the various channels has been

indicated above, but no unequal distribution of pigment has been observed which would in any way correspond to the unequal distribution beneath the pleura. True it is, however, that certain pathological processes in the lung tissue may modify the distribution of the pigment to a very great degee. We have, however, failed to find any evidence of excessive deposit in the deep tissues at the apex of the upper lobe. In fact, in our experience more pigment was found toward the hilus than at the periphery, regardless of the pleural distribution. Furthermore, the more marked areas of pigment deposit in the pleura are confined to this superficial layer and do not involve the underlying parts.

In several specimens of lungs from elderly individuals, who showed a moderate amount of emphysema in portions of the lobes near the surface, it was observed that an unequal distribution of the anthracotic pigment was present. Those lobules showing emphysema contained less pigment than elsewhere. This condition was not only apparent by the greater area occupied by the emphysematous tissues, but was real, in indicating less carbon in the affected tissues. When such emphysematous areas occupy the surface alveoli and when these lie upon the ridges of the costal markings, it is then found that the borders of the grooves contain less pigment than the surrounding areas. Thus the contention of Marchand and others that the ridges between the intercostal grooves accumulate less pigment may have its explanation in the presence of these emphysematous alveoli.

THE MODIFICATION OF ANTHRACOTIC DEPOSITS BY OTHER FACTORS.

It is evident from what we have said, that every individual has a greater or less quantity of carbon accumulate in the lungs, and that this accumulation varies in the normal lung according to the amount of carbon in the inspired air. With advancing age, the quantity of pigment continues to increase until a relative standard for

the community in which he resides is reached. This pigment in the normal lung becomes deposited, through the agency of phagocytic cells, within the lymphatics and its particular location beneath the pleura of the lung, is dependent upon the distribution of the lymph channels and the relationship of the opposed pleural surfaces which varies to some extent in all individuals. The distribution within the normal lung substance appears to be entirely determined by the circulation within the lymphatics.

Whereas under normal conditions we may look for certain common features in the anthracotic deposits in the lungs, there are also pathological processes which bring about a modification of the deposit. Thus we find that certain disturbances within the lung tissue have an effect of inducing greater deposits of pigment within localized areas. And it is probable that this new condition of excessive pigment deposit brings about further changes instituting a vicious circle.

A. LOCAL PLEURAL INFLAMMATION.

It is not an infrequent observation to find a greater quantity of pigment in the immediate vicinity of a band of pleural adhesions. By some it has been suggested that these adhesions are the result of the unusual deposit which leads to an excessive irritation in the surrounding tissues. When, however, we study the development of pleural adhesions we find that the fibrous bands in children show little or no difference in the deposit of pigment from other parts of the lung. With advancing age, however, the accumulation of carbon at the point of attachment of the adhesion to the lung becomes greater. A difference is noted, too, in the character of the adhesions, for those which have only a superficial attachment and do not induce a fibrosis of the neighboring lung tissue, show less deposit. It is obvious that we must differentiate those pigmentary processes associated with primary pleural adhesions from those that we associated with primary lung

disturbances (tuberculosis), in which adhesions may also be present. Of this latter type, we shall speak again.

The best example of pleural adhesions for study are those developing between two surfaces which are in constant frictional contact, as well as the bands of adhesions which sometimes follow fibrinous pleurisy in early life. Of the former type we meet with adhesions at the apex arising from a rib groove which, under ordinary circumstances, is non-pigmented. Here a firm band of adhesion binds a portion of the lung to the chest wall. The fibrous band not alone attaches itself to the surface of the visceral pleura but bands of tissue enter to a greater or lesser extent the fibrous layer of the lung covering and the interstitial septa, and alveolar walls. The fibrosis spreads diffusely through the tissue surrounding the blood vessels and encroaches upon the loose tissue of the lymphatics. Some of the lymph channels become completely obliterated, others are altered in their course.

It is probable that some of these bands of adhesions develop without the presence of an acute process and like the presence of milk spots of the heart, induce a progressive fibrosis which alters the relationship of the surrounding tissues. The pleura with its vascular tissues is altered to a sclerosed structure in which the lymph channels are reduced to mere clefts. In this condition not only is there a stasis of the fluid within these channels, but there is also a filtering out of the phagocytic cells which are constantly wandering from the alveoli towards the larger lymphatic system at the hilus. Gradually the accumulation of cells is sufficient to show the increased quantity of pigment within the part. It would appear according to Haythorn, that these migrating cells may live for a considerable period with the pigment within their protoplasm. Other phagocytes probably liberate their contents which become deposited in the interstices of the fibrosed areas. It is probable that the liberated carbon remains in the clefts between the cells and does not enter fixed tissue cells.

If the opportunity for the absorption of carbon pigment from the alveoli be great, then the accumulation of this foreign material in the vicinity of adhesions becomes very marked. Nodules are formed which are hard and encroach upon the lung tissue. The lung alveoli are surrounded by a progressive fibrosis containing much carbon. It is more than probable, that when such excessive quantities of pigment are deposited that these again act as irritants, inducing greater adhesions. We do not believe that the inhalation of carbon in the normal lung will induce pleural adhesions unless some other factor within or upon the lung acts as a primary exciting cause. We have upon repeated occasions observed the lungs of mill workers and coal miners in whom the lung tissue had become intensely black through carbon deposit without there being any evidence of pleural adhesions.

We have never observed acute pleurisy to alter the deposit of pigment in the pleura. It has been observed that in acute inflammatory processes where the lymphatic channels of the pleura are filled with migrating and phagocytic cells that a considerable amount of pigment may be removed from the pleura to other parts. The exact bearing which this inflammatory migration might have upon the total pigment content could not be determined. The changes, however, were insufficient to produce any difference in the amount of pigment to be noted by the naked eye.

On the other hand, the chronic processes of the pleura not uncommonly had an effect similar to that observed associated with individual tags of adhesions. In cases where there were universal fibrous adhesions, the effect was not observed in the quantity of pigment deposit except where denser bands had developed. The diffuse and veil-like adhesions were without change in the vicinity of their attachment to the lung. A study of these indicated that the fibrous tissue of these adhesions had only a superficial attachment and did not involve the deep layer of the pleura. Where, however, the intensity of the chronic adhesive pleurisy was not uniform and where irregular bands

were attached to the lung substance at various points, here a more marked pigment deposit was prone to form.

In all instances where the more intense deposit of carbon pigment was associated with bands of adhesions, the process remained fairly superficial and localized. There was no invasion of the deeper parts by the continuous accumulation of pigment.

B. INFLAMMATION OF THE LUNG SUBSTANCE.

Much has been indicated to associate pneumokoniosis with acute and chronic respiratory diseases. As early as 1717, Ramazzini drew attention to certain air borne occupational diseases, and since then the greatest attention has been paid to diseases associated with inhalation of dust. Naturally, much interest has centered about the effect of inhaled dust of various kinds upon the lung and more particularly the relation, if any, that existed between these changes brought about by the deposits and inflammatory processes induced by bacteria. The manner in which this relationship was established has not been entirely clear. By many (Ascher and others), however, tuberculosis has been looked upon as a process secondary to the deposition of the dust.

On the other hand, the relative infrequency of pulmonary tuberculosis amongst those who are engaged in work associated with much coal dust, has been pointed out by a number of authors (Ogle, Sommerfeld, Hirt). In the statistics, tuberculosis appears rather rare among coal miners. It would, therefore, appear that the inhalation of coal dust does not predispose to tuberculosis. The explanation for this appears to depend upon the morphological characters of the dust particles. On the other hand, Kuborn, Villaret, Versois, and others believe that the continued contact with coal dust leads to a true immunity against tuberculosis. Racine believed that coal contains substances which are antiseptic and disinfectant and that this quality inhibits the growth of the tubercle bacilli, and Holman has shown similar disinfectant qualities in

soot. Another (Idel) believed that the porous coal dust absorbed the tubercle bacilli and rendered them inert, while Wainwright and Nichols thought the partially soluble calcium salts contained within the coal gave the animal body protection against these organisms. The indication that the presence of coal dust within lungs had a favorable effect upon respiratory diseases, led Guillot to use the inhalation of coal dust for therapeutic purposes. As early as 1793 Beddoes established a sanitarium near Bristol where he treated chronic diseases, as asthma and consumption by the inhalation of charcoal. The patients were placed in a dusting box where by mechanical means the charcoal was distributed into the air. However, it was later shown by Papasotiriu that coal dust had no influence upon the growth of the tubercle bacilli upon glycerine agar cultures, while Cornet was unable to protect animals against air borne tuberculosis by means of the inhalation of carbon dust. It has been indicated by Bartel and Neuman that anthracosis increases the virulence of tuberculosis in experimental animal infection.

It is more than probable that the infrequent presence of tuberculosis amongst those developing extensive anthracosis has its explanation in certain anatomical changes in the respiratory system and it is possible, as is indicated by Fraenkel and admitted by Racine, Wainwright and Nichols, that the infrequence of progressive tuberculosis among the coal miners is due to tissue obstruction of the lymphatic channels brought about by the anthracosis.

Ascher's observations that the extensive inhalation of smoke as well as soft coal increases the mortality in tuberculosis, is not in agreement with other general findings. It has, however, been shown by Hart that there is a difference in the composition of smoke particles and coal dust, and that the former contains some of the products of coal distillation. Again it has been shown by others that laborers engaged in atmospheres containing much coal dust, such as stokers, coal heavers, and chimney sweeps, are just as immune as coal miners to tuberculosis (Markel, Versois). Lewin found that 92.3 per cent. of chimney sweeps

who had followed this occupation for more than 10 years were free from respiratory diseases.

Our own observations have concerned themselves in determining the influence of the pigment upon the lung tissue as well as its relation to the tissue changes in acute and chronic processes within the lung. We can offer no statistics which show the relation which the pigment deposit has to the occurrence of infections of the lung. This study also deals with the effect of certain respiratory diseases upon the subsequent deposition of carbon pigment.

As it has been shown that the anthracotic material owes its presence to the activity of certain phagocytic cells it is evident that an interesting problem confronts us in determining what role similar cells stirred to activity by a bacterial irritant will have upon the foreign materials, as carbon pigment, which are already present in the interstitial tissues.

In the study of lung tissues showing acute pneumonia one is confronted with the picture of a lesser pigmentation in the areas involved in the pneumonia. The appearance is quite decided and a fairly sharp line of demarcation separates the pneumonic area from the more healthy tissues. Within the consolidated portion of the lung the carbon pigment is seen only in the more prominent nodular deposits while the pigment observed along the interlobular septa in the normal lung can no longer be traced. The diffuse pigmentary deposit in the alveolar walls is also overshadowed by the color of the exudate, be this grey or red. However, when viewing the lung from its pleural surface no change in the amount of pigment deposit is observed in the superficial portions.

Although a decided diminution of pigment within the consolidated area is apparent, the fact that pigment is actually removed from the tissue involved in the inflammatory process can not be demonstrated in the lung after its recovery from pneumonia. We have not been able to define the areas of consolidation after recovery from the disease, by the amount of pigment in the tissues.

It does seem, however, that some of the pigment in the lung tissue becomes dislodged during the active migration of cells. During the late stages of pneumonia, the lymphatic channels contain a greater number of pigment bearing cells than are observed in the uninvolved lung. It may be that, due to the stagnation of the lymphatic system in anthracosis, these pigment bearing cells do not have an opportunity of migrating from the pulmonary structures, but remain stagnant in the dilated lymph channels. The macroscopic appearances of a diminution of carbon pigment during the acute stages of the pneumonic process is more apparent than real and is due to the overshadowing of the normal lung structures by the cellular exudate of the inflammation.

On the other hand, we have repeatedly observed that in isolated areas of fibrosis of the lung where no evidence of tuberculosis was found that the amount of anthracotic pigment was much increased over that present elsewhere in the same lung. We can, however, hardly offer this as an indication that the sequel to an acute inflammatory process, ending in fibrosis is associated with an excessive pigmentary deposit. In a single case of well advanced organized pneumonia we observed some increase in the amount of macroscopic pigmentation within the fibrosed area as well as microscopic evidence of such increased deposit. Naturally, it is difficult to estimate the exact variations from the normal deposit in different parts of the same lung.

In no instance has the examination of pneumonic lungs shown that the presence of the anthracotic deposit has in any way modified the distribution of the acute process. It can not be shown that the more intensely pigmented tissues are more readily subject to pneumonia than the other less involved areas. It has, however, been suggested by Haythorn that aside from the local pigmentation in the vicinity of the individual air sacs, the anthracotic process of the lung has a definite effect upon the lymphatic system and particularly the lymphatic channels. These channels, which become narrowed and partly obstructed,

are less efficient for carrying off the debris which accumulates in the acute inflammatory process. This stagnation impairs the process of resolution with the result that proper repair of the lung following pneumonia does not take place. Conditions of unresolved pneumonia and gangrene of lung are more common in lungs with marked anthracosis than in the less affected organs.

We have in many examples made observations upon the anatomical relationship between the anthracotic deposit and tuberculosis. It is immediately apparent that in the discussion of such a relationship we must clearly define the type of tuberculosis. Naturally, the effect of the distribution of the tuberculous process upon the anthracotic deposit will be different in acute miliary tuberculosis than in chronic localized tuberculous lesions, and similarly the reverse relationship, if such exists, will also differ with the various forms in which one meets the tuberculous process. Individually both processes are dependent, for their local distribution, upon similar factors, the phagocytic activity of cells and the distribution of the lymphatics.

We have not been able to observe any direct bearing of the anthracotic process upon acute miliary tuberculosis, nor have we observed a greater tendency for the development of tuberculous lesions in the anthracotic areas than in other parts of the lung. In fact, lungs showing moderate anthracosis will have more acute miliary tubercles in the uninvolved portions of the lung than in the anthracotic nodules. Nevertheless, we have observed that in the later stages of the process when the miliary tubercles had advanced to larger and more definite caseating areas that the localized areas of anthracosis not infrequently had gray tuberculous centers. It is probable, therefore, that the absence of tubercles within anthracotic nodules during the acute stage of the infection is, in part, due to the intense pigmentation obliterating the early tuberculous focus. As the anthracotic deposit is associated directly with the course of the lymphatic streams and particularly with those surrounding the blood vessels, it is to be ex-

pected from what we know of the distribution of tuberculosis that many tubercles will develop along these systems, in spite of the presence of anthracosis. As the individual miliary tuberculous foci increase in size they gradually obliterate the anthracotic areas with the change from an intensely pigmented tissue to one showing numerous gray nodules of various sizes. With the increase in number, the tissue gradually loses the intensity of its pigmented appearance.

A still more marked loss of anthracotic pigment from the lung is seen in caseous pneumonia. Here, instead of having many small gray nodules gradually obliterating the pigment within the lung, we observe a diffuse gray caseous tissue whose light color is in strong contrast to the pigment in other portions of the lung. Only a moderate amount of pigment deposit is seen in the caseous area, and this pigment lies in the areas of former intense deposit. The gray color of the caseous areas not only represents the necrotic exudate within the alveoli, but also indicates tissue changes, first proliferative, later degenerative of the alveolar walls, and their contents. It is during the process of proliferation in the alveolar walls and lung trabeculae that the former pigmented cells are stimulated to proliferation and probably migration, which leads to a removal of the pigment in the particular area. What eventually becomes of the disturbed pigment in the lung tissue during the tuberculous process is difficult to say. In part, it finds its way towards the lymphatics at the hilus of the lung. In part, it may become removed by the destruction of the tissue and subsequent expectoration.

In the above processes, acute miliary tuberculosis and caseous pneumonia, it is evident that the anthracotic process has no influence in localizing the infection. We have, however, observed that miliary tuberculosis is more prone to develop into a chronic caseous miliary form in lungs presenting much pigmentation than in those not affected.

Quite a different outcome is observed in localized chronic caseous tuberculous foci. The early stages of the

tuberculous process simulates the lesions which we have just described. As the lesion enters the chronic stage one observes that instead of there being a diminution of pigment in the involved area that gradually and in direct proportion to the amount of fibrosis the pigment deposit increases. Thus the periphery of the lesion in which area the healing of the tuberculous mass is taking place, larger amounts of pigment are continuously laid down. We have never observed the macroscopic increase of pigment before the development of fibrosis in the tuberculous lesion. Eventually the fibrosed mass becomes intensely black and hard. These areas vary in size from a pea to a mass the size of a golf ball. When fully developed the tissue with its pigment deposit resembles in consistance and color a hard rubber ball.

We have observed all stages of these pigmented masses surrounding tuberculous foci and it is evident that the pigment deposit develops upon the tuberculous lesion. The extent of the pigmented area is entirely dependent upon the reaction in the tissue of the tuberculous focus, and this reaction is always of the development of fibrosis. Where a tuberculous process by progressive caseation has lead to cavity formation there is no excessive pigmentation in the vicinity of the cavity until repair by fibrosis has begun in its walls.

Microscopically, it has been shown that the same cells, which form the tubercle and which in themselves are phagocytic for tubercle bacilli, are also the cells most phagocytic for carbon pigment. Thus these cells, constituting the tubercle, are adapted for the localization of foreign dust particles, and being in excess of the number present in the normal parts of the lung, may bring about an anthracotic deposit, with the tubercle. However, by the time the pigment has accumulated in sufficiently large quantities to be recognized macroscopically, there has developed a secondary fibrosis inducing a vicious circle by obstructing new lymphatics and accumulating greater numbers of pigment laden cells.

TISSUE CHANGES INDUCED BY CARBON PIGMENT WITHIN THE LUNG.

To-day we have come to recognize that the term anthracosis does not refer alone to the presence of coal pigment within the lung, but also includes the tissue changes which accompany this deposit. As we have previously indicated we have come to recognize that the deposition of the carbon in the lung is brought about through the agency of phagocytic cells. It is not probable that inert carbon can enter the lung tissues by mechanical means alone. The contention of Klein, Sikorsky, Merkel and others that the physical characters of the foreign material is such that it may migrate between the cells in the alveolar walls without the assistance of wandering cells can no longer be supported. Hence it is evident that the very process of accumulating and carrying the pigment is a vital one and has to do with the cells arising from the pulmonary tissues. It has been shown that the number of cells acting as phagocytes found within the alveoli is proportionate to the quantity of pigment in the air sac and thus, too, the activity of the wandering cells is dependent upon the inhaled carbon. As the engulfed pigment is prone to remain fixed for considerable periods of time, it even being claimed by some that the phagocyted pigment remains permanently within the wandering cells, there is a progressive accumulation of these cells in the lymph spaces of the alveolar walls. Their direction is mainly towards the larger lymphatic system at the hilus of the lung, but it is also probable that these cells may not only lie inactive for varying periods of time, within the interstitial lymph spaces, but are still capable of returning to the air sacs to encumber themselves with still more foreign material.

How long these cells of an endothelial type are able to remain dormant but still living, is very difficult to say, yet it has been demonstrated in tissues that pigmented cells having every appearance of fixed connective tissue

when thoroughly analyzed and segregated from their surroundings were found to be endothelial cells.

It is the common observation to find a progressive accumulation of pigment bearing cells within the alveolar walls with advancing ages. As the cells increase in number within the lymph spaces the wall becomes thicker and the tissue has a more or less hyaline appearance between the aggregations of pigment granules. To a certain extent the increase in tissue is the result of a direct increase in the number of wandering cells. On the other hand, we have also been able to show that there is a definite increase in the connective tissues about the lymph channels with the laying down of heavy collagen strands.

With this fibrosis there is no increase in the elastic tissue, in fact, the areas of extensive change are poorer in elastic fibers than normal.

As we have previously indicated the distribution of the inhaled dust in the lung is quite uniform, save for its distribution in the lymphatics of the pleura. Some (Arnold and also Boer) maintain that the deposition of soot is considerably greater in the upper lobe. This has not been our finding, though at times a difference has been observed between the two lungs. The accumulation of dust to that extent which induces secondary fibrosis will thus give rise to a fairly uniform tissue change in all lobes of the lung. This is a common finding in as far as the lung tissue proper is concerned. It is probable that the fibrosis thus produced assists further with preventing a proper lymphatic circulation (Haythorn) and leads to the greater number of phagocytic cells becoming localized in the alveolar walls.

It is probable that the very nature of the phagocytic cells, being large and sluggish in activity, leads to their more ready localization in the lymph clefts than the more active leucocytes which deal with acute disturbances. If the normal functions of the endothelial phagocytic cells would be continuously carried out, it is improbable that as great a quantity of carbon would localize in the parenchymatous tissue of the lung, more of it finding its way

to the large lymphatics and lymph glands at the hilus. The very condition which is brought about by the obstruction of the lymph clefts and small channels as well as the blocking of the lymph sinuses in the nodes about the bronchi tends to increase the localization of the large phagocytes close to the alveoli from which they obtain their pigment. Thus the nature of the pigment phagocytosis and the localization within the lymphatic spaces tends to bring about a vicious circle which, when a certain degree of anthracosis has developed, permits of a still more rapid deposit of pigment in the alveolar walls. It is about in this stage of the condition that the developing fibrosis leads to structural changes which impair the function of the lung tissue.

Other than inducing a diffuse fibrosis within the lung, there are also the nodular fibrotic masses surrounding accumulations of pigment and pigment bearing cells at the junction of the lymphatic channels. The more common of these are the size of wheat grains. The fibrosis assumes a concentric arrangement enclosing pigment which to a great extent lies free but much of which is contained in the original phagocytic elements. Such nodules, however, may become much larger, forming isolated masses, three or four cms. in diameter. It is probable, however, that these larger masses arising in the lung tissue have had other factors superadded, leading to their unusual development. The consistence of these is that of hard black rubber. Where calcareous masses are found in the center of such nodules, the previous existence of tuberculosis is strongly suggested. This association of anthracosis with chronic tuberculosis we have discussed above.

ANTHRACOSIS AND EMPHYSEMA.

With extensive and diffuse development of pulmonary anthracosis in which tissue changes to a greater or less degree are developing, the activity of certain parts of the lung is impaired to such a degree that compensatory changes occur in other and more active parts. These com-

pensatory changes are mainly evidenced in the development of emphysema. It would be difficult to indicate the sequence of events in laborers or coal miners. Here, from the very nature of their work emphysema would readily occur. We may, however, observe emphysema in individuals with diffuse anthracosis whose work or whose thoracic condition would offer no explanation, for the compensatory expansion of certain lung areas. This we have on several occasions observed and we were unable to find an explanation save in the diminished functional activity in those portions of the lung with marked anthracosis and fibrosis. The development of the emphysema observed in the positions is seen under other conditions.

The apex and the anterior border of the upper lobe are usually most involved. A rather remarkable feature associated with this emphysema is the disappearance of the anthracotic pigment from the emphysematous area. Where the alveoli become usually distended the pigment gradually disappears until the tissues look quite white (pulmonary albinis). This has been commented upon by Beitzke and others.

From our observations it would appear that this loss of pigment from the lung is the result of the greater local activity during the process of development of the emphysematous areas. The condition would simulate the lack of pigment observed in the interlobar pleura where the massage of these areas by constant friction seems to drive the pigment bearing cells into the larger lymphatics. This is probably also the case during the development of the emphysema where the lung alveoli are acted upon by the greater air pressure having the effect of repeated compression and relaxation. Thus the air contained within the alveoli has the effect of massaging the alveolar walls and likewise of driving onward the cells containing the pigment. A similar effect would also be had upon the free pigment within the lymphatic spaces of the alveolar wall. In these emphaysematous areas the removal of the pigment is not associated with an inflammatory process assisted by leucocytic phagocytes.

QUANTITATIVE ESTIMATION OF CARBON IN LUNG.

As we have indicated, a fair estimate for comparison can be made of the carbon deposit by the naked eye appearance. The pleural deposit of carbon, although not directly related to the presence of pigment in the inner portions of the lung, is, nevertheless, a good guide to the quantity of foreign material in the organ. The pale gray or grayish-pink color of the lung of the rural inhabitant is readily distinguished from the mottle, streaked or slaty black tissues of the city dweller. Moreover, as we have indicated, the progressive increase of the carbon deposit, in the lungs of every citizen in manufacturing communities, can be recognized and grouped into the age periods by decades, when the individual has lived fairly constantly in the same district. Individuals of similar occupation are exposed to relatively equal amounts of atmospheric carbon, and their respiratory tissues receive similar quantities of carbon by inhalation. On the other hand, in communities where within short ranges of distance the atmospheric conditions differ, and with this the carbon content of the air is very unequal, the peoples living or working but short distances apart are subjected to diverse conditions, the one inhaling much larger quantities of soot than the other.

There are so many factors associated with the deposit of soot in the lungs of human individuals that it is impossible to make any general statement indicating the amounts for each. In truth, it is plain that those in smoky atmospheres have larger deposits, but we are often misled in our reference as to occupational influence. The millworker employed within the sheds in the manufacture of steel is often less exposed than his wife living within a quarter-mile range enveloped by the smoke clouds from the multitudinous stacks. The lungs of a peddler selling his wares to the foreign population of our smoke-laden valleys

were found to contain more carbon than those of the mill-hand (see table below).

As we feel convinced from our observations, that the intestinal route has little or no practical significance for the deposit of carbon in the lungs, it does not appear that the degree of cleanliness—particularly of the mouth—bears any relation to pulmonary anthracosis. Carbon particles once lodging upon the moist surfaces of the nose, mouth, pharynx and trachea, never assist in increasing the carbon of the lung. It is probable, as was shown by Haythorn's experiments, that only those carbon particles lying within the alveolar sacs can reach a permanent interstitial abode and that little if any carbon is phagocyted and carried into the tissues from the bronchi or bronchioles. Furthermore, it would appear, both from experimental and other observations, that the carbon reaching the lung alveoli is only a very small portion of the carbon content of the air as inspired, and this portion has reached the lung because it escaped contact with the moist mucous surfaces of the respiratory tract. Under the most trying circumstances of a smoky atmosphere we are amply protected by the sticky surfaces of tortuous tubes.

Difficult as it seems for carbon to reach the lungs, it appears equally difficult to dislodge the pigment when once it has been incorporated by the tissues. In fact, we may well believe that, save under very abnormal circumstances, carbon once within lung tissue remains for life, and hence each year we add that amount to our store as we may have been exposed to city smokes. To gain some accurate information of the quantitative deposit of carbon in the lungs an analysis was made of the tissues. Previous analyses have been made determining the quantity of iron, sillicate, copper and other metalic deposits in the lungs of laborers.

Saito in a series of experiments estimated the quantity of dust inhaled from the air. Using measured quantities of dust (white lead) he determined the quantity taken up the animal when exposed to the dust-laden air. He observed that only 4 to 24 per cent. of dust entering the

nose was deposited in the respiratory organs, while the remaining quantity found its way to the intestine.

More recently Boer has made a relative quantitative estimation of the soot content of small portions of lung tissue. By his method, using only 3 ccm. of lung tissue, errors of calculation may possibly be great. He points out the error which would be obtained in comparing lung tissue of unequal density or consistence, as for example that of emphysema or oedma, and confined his examination to normal lung tissue. Here, too, much variation may be encountered, whether or not much pigmented pleura is included in the portion under examination. Care in selection of the tissue can not wholly rule out errors of serious import in the results. Furthermore, as the amount of carbon in these small portions of tissue was too small to weigh, he has used a colorimetric method suggested by Liefmann. The amount of carbon isolated from the lung examples was suspended in a mixture of oil and ether, and compared with a set of standard suspensions, prepared by suspending weighed quantities of naphthalin soot in the same vehicle. Such a colorimetric method cannot be relied upon, owing to the difference in the nature of the carbon in the lungs and naphthalin soot. Fresh soot has physical and chemical properties widely different from the carbon isolated from the lung by treatment with antiformin and alcohol. Isolated carbon from lungs has lost its flakiness and is quite granular, devoid of its phenols and acids. Its bulk is much less than the original soot from which it was derived, and in suspensions taken, weight for weight, it does not compare with the apparent mass of soot. It is furthermore, to be noted that in isolating the lung carbon, care must be taken to free the final product of its fat and foreign calcareous matter which tends to remain incorporated in the residue.

In our determinations we took an entire lung, dissected away the glands, large bronchi and adventitious tissue at the hilus, and minced the entire organ in a meat machine. The pulp was then divided among four half-liter flasks and to each was added enough of a seventy-

five per cent. solution of antiformin to well fill the flask. The flasks were placed in the incubator and repeatedly shaken for four to six days. Two hundred cubic centimeters of alcohol were then added to each flask and the mixture centrifugalized, the residue being collected and returned to clean flasks. These materials were again subject to fresh digestion with antiformin for a period of four days, recollected, washed and for a third time acted upon by antiformin. After again collecting the residue and washing it, it was treated with ten per cent. hydrochloric acid, repeatedly agitated and allowed to remain in contact for forty-eight hours. The residue now collected by the centrifuge and washed, was in turn treated with acid-alcohol and ether until the supernatent fluid showed no evidence of fat. The ether suspension was then allowed to evaporate to dryness, and the collected residue repeatedly washed with distilled water to rid it of any contained salts. The final product consisted of a pure black, fine powder, denser than the light, fluffy soot masses found in the air. Under the microscopic, angular carbon particles were alone present.

Case	Age	Occupation	Residence	Side	Quantity of Carbon
218	22	Laborer	Pittsburgh	Right	3.2
73	28	Peddler	"	Left	5.3
154	37	Laborer	" (6 yrs.)	Right	1.7
163	37	Housekeeper	"	Right	2.1
158	39	Clerk	"	Left	1.2
164	44	Housekeeper	"	Right	2.6
A-Q-8	47	Storekeeper	Ann Arbor	Right	0.145
A-Q-12	68	Laborer	"	Right	0.405
239	69	Carpenter	Pittsburgh	Right	2.81

(NOTE.—I am indebted to Prof. A. S. Warthin for the material from Ann Arbor.)

In our examination it is shown that the lungs of adult individuals resident in the Pittsburgh district have materially more carbon deposit than the lungs of the two individuals resident in a lesser manufacturing community.

Our number for comparison is very small, but is, nevertheless, suggestive of community characteristics. On account of the slow and rather tedious process in isolating the carbon in a pure form, only one lung was examined in each case, so that the total pulmonary content is about double of that indicated in the table. Furthermore, it is to be noted that the isolation of the carbon did not include that present in the peri-bronchial glands, where dense deposits are commonly found.

As was previously indicated the lungs showing marked anthracosis are decidedly heavier than normal organs, but it must not be inferred that the extra weight is due to the foreign dust in the lungs. From our analysis of the carbon pigment in the lung it is evident that no material increase in weight is obtained directly from this source. On the other hand, it is well shown that a relatively small quantity of carbon in the lung can induce massive fibroid changes which alter the architecture and increase the bulk.

SUMMARY.

Pulmonary anthracosis (not in coal miners) is distinctly an urban disease, and is proportionate to the smoke content of the air.

The soot is inspired and lodges in the pulmonary alveoli, from which it is carried by phagocytes into the lung tissue to become lodged in some portion of the pulmonary lymphatic system.

Although small quantities of carbon deposit in the lung may remain without harm, yet the quantity accumulating in the dweller of the larger cities has an accompanying greater or less fibrosis impairing the elasticity as well as altering the functional capacity of the organ.

The distribution of carbon is fairly uniform in the parenchyma of the different lobes, but there is a considerable variation in the distribution of the pleural deposit. The interlobar and diaphragmatic pleural surfaces show the least pigment. Moreover, less pigment is found in the grooves produced by the ribs or abnormal bands.

Carbon tends to accumulate at the nodal points of junction of the lymphatic channels. The cellular migration of carbon may lead to unusual accumulations in certain areas particularly well demonstrated in the deposit about chronic tuberculous lesions.

Carbon deposits by inducing fibrosis tend to encapsulate chronic tuberculous foci.

Pulmonary anthracosis by itself does not appear to stimulate the production of pleural adhesions.

The actual amount of carbon present in the lungs of different individuals varies considerably and is dependent, in part at least, to the age, occupation, residence and condition of the lungs (emphysema, collapse, tuberculosis).

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The Bacteriology of Soot*

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The study of soot from a bacteriological standpoint has received but scant attention from the numerous investigators of the problems of the smoke nuisance.

Needless to say the subject has not been left out of the discussions; in fact, it is rather frequently mentioned in a more or less general way. As far as I have been able to ascertain, however, there has been but little definite work on the Bacteriology of Soot as discussed in this paper.

In an article in the *Revue Industrielle* (1), is found the question, "Are we going to learn one of these days that smoke, thanks to its antiseptic properties, contributes to making the atmosphere healthy?" Glinzer (2) refers to the fact that the particles contained in soot possess excellent germicidal and disinfecting qualities. Racine (3) in a discussion on the "Relation of Emphysema and Tuberculosis to coal-lungs in miners," believes from his own observations that anthracosis of the lungs acts as a protective influence against tuberculosis and that the only correct view is that coal has a great disinfecting power and that the conserving action of the coal dust is, perhaps, to be explained "from its action as a hinderance to the growth of microorganisms such as the bacilli of tuberculosis." We were unable to find in the literature any original work upon which these conclusions could be founded. Percy Frankland (4) shows that fogs do not tend to con-

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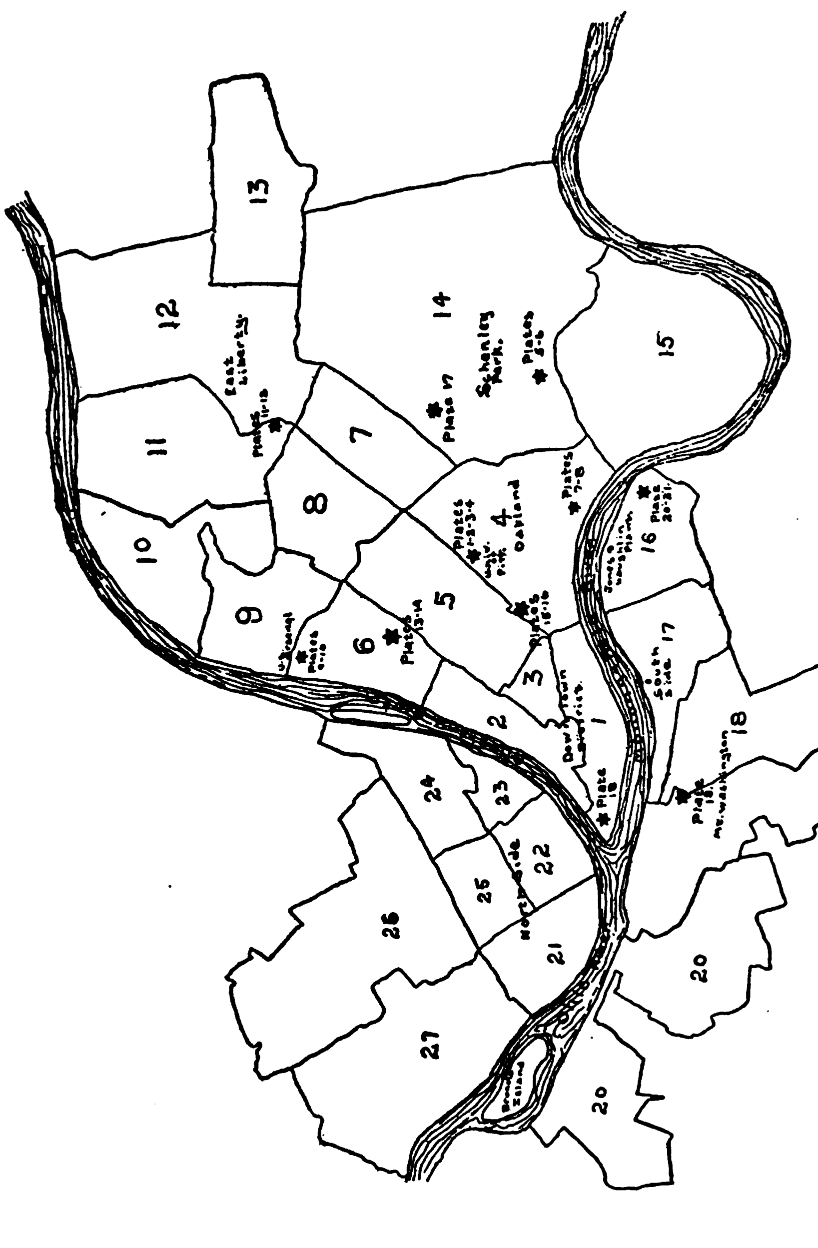
centrate or nurture bacteria, for he found there were remarkably few bacteria in London air during a fog. On the other side of the question, Russel (5) includes the increased number of bacteria in a list of contributory causes of the high death rates during fogs. Sir William Ramsay (6) first brought forward the theory that smoke by directly absorbing light, through the action of clouds and fogs, which are particularly fitted to absorb the blue, the violet and ultra-violet rays, which are the germicidal rays in light, contributes to the development and increase of bacteria, pathogenic as well as others, in the atmosphere. Liefmann (7) also believes that under the above conditions "bacteria, especially the pathogenic ones, are permitted to thrive." In passing it may be mentioned that there is no evidence that bacteria ever grow in the air. They are carried into it from a variety of sources, are continually falling out of it by gravitation, being carried out by rains, or destroyed in a number of ways. The effect of the gases in the air upon bacteria is another problem, although it is closely related to the one under discussion. The contamination of the air of our cities with sulphur dioxide is well known (8); also that surphur dioxide in the air acts as a disinfectant, the necessary proportion being not less than 92 grams of sulphur per cubic meter (9). Cohen and Ruston in "Smoke—A study of town air," have devoted some space to the consideration of the effects of acid rains upon the bacteria of the soil. They point out that the greatest reduction takes place in the numbers and the activity of the nitrifying or nitrate producing bacteria, there being also a marked inhibitory effect on the nitrogen fixing organisms.

In our investigations we examined the air of Pittsburgh to determine the numbers and distribution of bacteria in different parts of the city and to ascertain, if possible, if any relation exist between the bacterial count and the smoke conditions.

For this purpose twenty glass evaporating dishes seven inches in diameter filled with agar-agar were ex-



MAP OF PITTSBURGH.

Showing Wards and Location of Agar Plates Exposed.

posed for from five to fifteen minutes in various districts. Notes were taken of the presence or absence of smoke, the wind direction, the condition of the earth, whether moist or dry, and time of exposure. The number of colonies developing in forty-eight hours at 37° C. varied within very wide limits and it was found impossible to discover any influence of the smoke content of the air on the bacterial count. The difficulty of attempting to draw any definite conclusions from these experiments will be patent to everyone, the factors which influence the bacterial content of the air being so numerous and so variable as—rain, moist or dry soil, winds, sunlight, and other conditions. The map of the city shows the points where plates were exposed and Table I gives our findings in a condensed form.

One quite striking observation, however, was made and that was the comparative infrequency of the development of colonies around the soot particles. Rough microscopic counts were made of the total number of visible soot particles and of those which were infected, as indicated by a black speck in the center of the colony. Out of about 500 counted, 100 showed growth. Many of these particles which we counted as soot, were, in all probability, specks of dust from other sources, so that our proportion of infected soot particles is too high. In several of the plates the soot particles were too numerous to count and around the majority of these no growth was to be noted. This was particularly true in the case of Plates 9 and 10, where the atmosphere was decidedly smoky. Considering the sources from which bacteria enter the air this is not to be wondered at. The smoke as it leaves the chimney is free from bacteria and apparently is not a favorable nidus for their collection from the air into which it is poured.

The common types of aerobic Gram positive spore-bearing bacteria and chromogenic organisms were isolated on our plates. B. Coli Communis and Communior, B. Alkaligenes Fecalis, B. Proteus Vulgaris, B. Pyocyaneus,

Plate Number See Map.	Time of Exposure in Minutes.	Weather.	Wind.	Smoke.	Count.	Notes.
1	15	Cloudy, rain 3 hrs. before.	N. W.	None	75	B. Coli Communis isolated.
2	15	Cloudy, rain 3 hrs. before.	N. W.	"	53	
3	5	Cool, cloudy; soil damp.	W.	"	15	
4	10	Cool, cloudy; soil damp.	W.	"	68	
5	15	Clear, warm; soil damp.	W.	Blowing towards plates	26	B. Coli Communis. B. Coli Communior.
6	10	Bright sunshine; soil damp.	W.	but high.	43	B. Alkaligenes. Fecalis.
7	10	Cloudy, sultry; soil dry.	S.	Blowing towards plates.	51	5 soot particles, no growth.
8	15	Cloudy, sultry; soil dry.	S.		144	15 soot particles, 3 infected.
9	10	Partly cloudy.	S.	Smoky.	60	Soot particles very numerous, 1 infected.
10	15	Warm, dry.	S.	"	108	Soot particles very numerous, 3 infected.
11	5	Clear, warm, sultry; soil dry.	S.	Hanging low.	18	Several soot particles, no growth.
12	15	Clear, warm, sultry; soil dry.	S.	Same.	46	Few soot particles; 1 infected. B. Proteus Vulgaris.
13	10	Bright, hot, dry, sultry.	S.	Valley smoke not dense	59	No soot particles. Nocardia.
14	15	Threatening rain.	S.	near plates.	—	Fly contaminated plate.
15	5	Threatening rain; rain 1 hr. before.	E.	Blowing towards plates.	116	B. Pyocyaneus. Soot particles 130; 14 infected.
16	8	Threatening rain; rain began.	E.	Same.	124	Soot particles 174; 17 infected.
17	10	Threatening rain; 2 hrs. before.	E.	Air smoky.	19	No soot particles.
18	10	Hot, clear, dry, dusty.	S. W.	Dirty, dusty, smoky.	196	Soot particles 11; 4 infected.
19	10	Hot, clear, dry, dusty.	S. W.	Valley smoky, clear near plates.	160	Soot particles 19; 11 infected; air nocardia.
20	5	Hot, clear, dry, dusty.	S. W.	Blowing towards plates.	131	Soot particles 72; 30 infected.
21	10	Hot, clear, dry, dusty.	S. W.	Blowing towards plates.	125	Soot particles 56; 14 infected.

and others, presumably from manure dust, and a few examples of air nocardia were also found.

Our next problem was to determine the action of soot on the growth of bacteria. For this purpose a quantity of soot was obtained from the special chimney in the Department of Industrial Research.

The partial analysis was as follows:

Tar,	3.84%
Ash	1.19%
Fixed Carbon	94.97%

This specimen was used throughout the experiments.

The analyses of specimens of soot collected from the air in different parts of the city showed some wide variations.

Woods Run.	
Tar	0.82%
Ash	62.6%
Fixed Carbon	36.58%
State Hall.	
Tar	0.36%
Ash	66.68%
Fixed Carbon	32.96%

This soot, even after standing around the laboratory in an ordinary cardboard box frequently open to the air, was shown by experiment to be almost free from bacteria. Five agar plates dusted with small quantities of this unsterilized soot failed to show growth with the exception of one colony on one plate. The soot was now added in varying amounts to test tubes of ordinary broth. No growth occurred. However, when larger quantities of this same soot were added to 150 cc. of broth in flasks, growth of bacteria did appear. The organisms developing being of the B. Subtilis group.

Experiments were next undertaken to determine the bactericidal action, suggested by the above observations.

Efforts were made to determine any difference in growth in flasks of broth containing soot from other control flasks without soot. Dilution and plating methods were employed but the mechanical interference of the soot particles in the one case ruled out the method as one without even approximate exactness. The counts, however, were uniformly lower in the soot broth than in the control. A series of agar plates, one having the surface sifted with soot, the other free, were next exposed in the laboratory and counts made of the colonies from the aerial contamination. No marked difference in the number of colonies was found.

The following series of experiments have, however, given us quite definite results indicating a very marked bactericidal action of soot. Five grams of soot were thoroughly mixed with 100 cc. of broth 0.6 acid to phenolpthalein. After autoclaving, the mixture was allowed to stand several days. The soot particles were then filtered out and the filtrate after sterilization was seeded with B. Typhosus. A control flask was inoculated at the same time. No growth occurred in the soot-treated broth while a good growth developed in the control.

A second experiment was carried out. The broth after treatment with soot as before was tubed and inoculated with a series of organisms. Controls of plain broth from the same batch were used for comparison. Fresh twenty-four hour cultures were employed. The results are seen in Table II.

The soot broth tubes which showed no growth after seeding and incubation, did not show any growth on further transfers with the exception of B. Subtilis. The spores in this case had most probably withstood the action of the bactericidal substance. B. Coli Communior and B. Indicus showed much less growth in the soot-treated broth than in the control. B. Pyocyaneus was apparently unaffected while B. Paratyphosus (Achard) and B. Proteus Vulgaris showed definite agglutination in the soot-treated broth.

TABLE II.

Culture.	Soot Broth.	Control.
Staph. Albus	—	+ + +
Staph. Pyog. Aureus	—	+ + +
B. Coli Communis	+ +	+ + +
B. Coli Communior	+ +	+ + +
B. Mucosus Capsulatus	+	+ + +
B. Acidi Lactici	—	+ + +
B. Typhosus (3)	—	+ + +
B. Typhosus (90)	+	+ + +
B. Paratyphosus B.	—	+ + +
B. Paratyphosus Achard	+ +	+ + +
B. Dysenteriæ (Flexner)	—	+ + +
B. Pseudodysenteriæ	—	+ + +
B. Iliacus	—	+ + +
B. Proteus Vulgaris	+ + +	+ + +
B. Alkaligenes Fecalis	—	+ + +
V. Cholera	—	+ + +
B. Pyocyaneus	+ + +	+ + +
B. Indicus	+	+ + +
B. Subtilis	—	+ + +
B. Mesentericus	—	+ + +
B. Xerosis	—	+ + +
B. Diphtheriæ (230)	—	+ + +

(The intensity of the growth is indicated by the number of + signs.)

We believed that this inhibitory and bactericidal action was due to the phenols contained in the soot. The soot-treated broth gave a marked reaction for phenols by Millon's reagent while the control broth gave a negative reaction. After testing the acidity, phenolphthalein being used as the indicator, it was found that the soot treated broth gave a difference of 1.7 per cent. acid over the untreated broth, the acidity of which was 0.6 per cent. To determine whether this acidity was the potent inhibitory factor we carried out the following tests.

A new lot of broth was prepared and the reaction made 0.6 per cent. acid. To 500 cc. of this broth 25 grams of soot were added. The mixture was thoroughly shaken, autoclaved and allowed to stand for two days, with repeated shaking and finally filtered. The reaction titrated against N/20 sodium hydrate expressed in terms of hydrochloric acid was found to be 2.2 per cent. acid. One-

half of the broth was used at this acidity, 2.2 per cent. the other half being reduced to 0.6 per cent. by addition of sodium hydrate. Half of the untreated control broth had its acidity raised to 2.2 per cent. acid with hydrochloric acid. The four lots were then tubed, sterilized and inoculated with a number of organisms from twenty-four hour agar slants. After an incubation of seventy-two hours, the results obtained were as shown in Table III.

From this it will be seen that we must consider at least two factors in the antiseptic action of the soluble content of soot in broth. The effect of the increased acidity which is seen most markedly in the cultures of the cholera vibrio where practically no growth took place in either of the acid broths is of great importance. The cholera organism is shown to be particularly sensitive to the presence of acid and for its cultivation an alkaline or neutral medium must be employed. Schroeder (10) has shown that the Vibrio choleræ is killed after an exposure of five hours to peat dust. It is especially effective, he says, if the peat be of an acid reaction.

The growth of B. Anthracis and B. Subtilis is also inhibited in the broths of high acidity, while B. Alkaligenes Fecalis and B. Iliacus, are definitely affected. It is interesting to note the effect of the acidity in interfering with the production of the coloring matter in the cultures of B. Pyocyaneus. Russel, Cohen and Ruston, and others point out the variable acid content of soot. On the other hand we notice, that, independently of the acidity, the soot-treated broth exercises a marked interference with growth. This is to be seen with B. Indicus, one strain of B. Coli Communis, B. Typhosus, and in B. Paratyphosus to a marked degree. The two latter organisms are not generally affected by small amounts of acid, and are, therefore, valuable in testing out this second bactericidal effect of the soluble parts of the soot.

Soot probably has the power of absorbing many gases from the air especially those associated with the combustion of coal.

The next problem was to study the effect, if any, of soot on the destruction of bacteria in the process of dessication.

TABLE III.

Culture.	Control Broth. 2.2 Acid.	Soot Broth. 2.2 Acid.	Control Broth. 0.6 Acid.	Soot Broth. 0.6 Acid.
B. Indicus	Heavy cloud	Trace of cloud.	Heavy cloud, heavy precipitate.	Slight cloud.
B. Pyocyaneus	Heavy cloud, powdery scum, trace of green color.	Same, no green color.	Same, bright green on top.	Heavy cloud, thick compact scum, green color throughout.
B. Anthracis	Clear, no precipitate.	Clear, no precipitate.	Clear, abundant precipitate.	Clear, slight precipitate.
B. Subtilis	No growth.	No growth.	Heavy ring, heavy precipitate, granular cloud.	Ring on glass, precipitate.
B. Coli Communis (52) and (14)	Marked cloud.	Slight cloud.	Marked cloud.	Slight cloud.
B. Coli Communis from urine (780)	Fair cloud.	Same.	Same.	Same.
B. Typhosus	Cloud.	Slight cloud.	Heaviest cloud.	Faint cloud.
B. Paratyphosus B.	Marked cloud.	Faint cloud.	Marked cloud.	Faint cloud.
B. Proteus Vulgaris	Heavy cloud, no scum.	Heavy cloud, scum.	Very heavy cloud, no scum.	Very heavy cloud, scum.
B. Iliacus	Slight cloud.	Fair cloud.	Heaviest cloud.	Heavy cloud and ring.
B. Alkaligenes Fecalis	Faint cloud.	Clear.	Marked cloud, scum.	Slight cloud.
V. Cholera	Clear.	Trace of cloud.	Cloud.	Cloud.

Dessication is one of the most valuable natural means of disinfection and many organisms succumb to its effects very rapidly as the gonococcus, the B. Influenza, the meningococcus and others. The micro-organisms of the air, on our streets, and in our houses are continually being destroyed by this process and we have been able, we believe, to show that soot increases very decidedly, this bactericidal action.

TABLE IV.

Exposure.	Influence of Soot on B. Indicus. Control. Cover Glass. Dipped in Broth and Dried.	Cover Glass I. Dipped in Soot while Moist, then Dried.	Cover Glass II. dried as in Control. Buried in Soot.
1 day..............	+	+	+
2 "	+	+	+
3 "	+	+	+
4 "	+	—	+
5 "	+	—	+
7 "	+	—	—
8 "	+	—	+

(The + sign indicates that growth was obtained in the test cultures.)

TABLE V.

Exposure.	Influence of Soot on B. Typhosus and Streptococcus Fecalis. Culture.	Control Dipped in Broth and Dried.	Cover Glass I. Dipped in Soot while Moist, then Dried.	Cover Glass II. Dried as in Control. Buried in Soot
2 days..........	B. Typhosus	+	—	
	S. Fecalis	+	+	
3 "	B. Typhosus	+	—	+
	S. Fecalis	—	—	—
	B. Typhosus	+	—	+
	S. Fecalis	+	—	+
4 "	B. Typhosus	+	—	+
	S. Fecalis	—	—	+
5 "	B. Typhosus	+	—	+
	S. Fecalis	+	—	—
6 "	B. Typhosus	+	—	+
	S. Fecalis	—	—	—
9 "	B. Typhosus	+	—	+
	S. Fecalis	—	—	—
10 "	B. Typhosus	+	—	—
	S. Fecalis	+	—	—

The technique of our experiments was as follows: Fresh twenty-four hour broth cultures of the organisms to be tested were prepared. Small sterile cover glasses were thoroughly moistened by dipping them into the cultures. These were dried under sterile precautions for sixteen to twenty-four hours over caustic soda. They were then transferred to sterile petri dishes and used as controls.

Cover glasses indicated under the heading I in the table, were dipped into the broth cultures and then into sterile soot and finally dried as in the control. Cover glasses under heading II in the table were prepared in the same way and at the same time as the control, and when dry were packed in sterile soot. From time to time these cover glasses were dropped into tubes of dextrose broth to test the viability of the organisms.

It will be noted that the failure of growth is shown very clearly in the case where the moist cover glass was dipped in soot and then dried. In the majority of cases those cover glasses which were first dried and then packed in soot failed to show growth much later than the above, but usually before the control. This is well shown in Table V.

The long period that the Streptococcus Fecalis, 174 days, and Staphylococcus Pyogenes Aureus, 225 days, remained viable under these abnormal conditions is quite remarkable. (See Table VI.)

In Table VII is shown the peculiar behavior of yeast. It survived longest, 41 days, on the cover glasses dipped in soot while still moist, the conditions under which all the other organisms tested rapidly died out. Marshall (11) quotes Hansen as stating that compressed beer yeast mixed and dried with charcoal kept as long as ten years. The marked resistance of the yeast organism to the action of acids is also of importance in this connection.

The great natural disinfectant of the atmosphere and our surroundings is the bactericidal action of the sun's rays. Direct sunlight is most destructive and its activity

TABLE VI.

Time of Exposure	Incubation Period	Influence of Soot on B. Coli, B. Typhi, Streptococcus Fecalis and Staphylococcus Aureus.			
		Culture	Control. Dipped in Broth and Dried	Cover Glass I. Dipped in Soot while Moist, then Dried	Cover Glass II. Dried as in Control. Buried in Soot
2 days	24 hours	B. Coli	+	+	
		B. Typhosus	+	+	
		Strep. Fecalis	+	+	
		Staph. Pyog. Aureus	+	+	
5 "	24 "	B. Coli	+	—	+
		B. Typhosus	+	+	+
		Strep. Fecalis	+	—	+
		Staph. Pyog. Aureus	+	—	+
	48 "	B. Coli	+	+	+
		B. Typhosus	+	+	+
		Strep. Fecalis	+	—	+
		Staph. Pyog. Aureus	+	—	+
6 "	24 "	Strep. Fecalis	+	+	+
		Staph. Pyog. Aureus	+	—	+
7 "	24 "	B. Typhosus	+	—	+
		Strep. Fecalis	+	+	+
19 "	24 "	B. Coli.	+	—	+
		B. Typhosus	+	—	—
		Strep. Fecalis	+	—	+
		Staph. Pyog. Aureus	+	—	+
	48 "	B. Coli	+	—	+
		B. Typhosus	+	—	—
		Strep. Fecalis	+	+	+
		Staph. Pyog. Aureus	+	—	+
34 "	24 "	B. Coli	+	—	—
		B. Typhosus	+	—	—
		Strep. Fecalis	+	—	+
		Staph. Pyog. Aureus	+	—	+
	48 "	B. Coli	+	—	—
		B. Typhosus	+	—	+
		Strep. Fecalis	+	—	+
		Staph. Pyog. Aureus	+	—	+

TABLE VI (*Continued*).

Time of Exposure	Incubation Period	Influence of Soot on B. Coli, B. Typhi, Streptococcus Fecalis and Staphylococcus Aureus. Culture	Control. Dipped in Broth and Dried	Cover Glass I. Dipped in Soot while Moist, then Dried	Cover Glass II. Dried as in Control. Buried in Soot
62 "	24 "	B. Coli	+	—	—
		B. Typhosus	—	—	—
		Strep. Fecalis	—	—	—
		Staph. Pyog. Aureus	—	—	—
	48 "	B. Coli	+	—	—
		B. Typhosus	—	—	—
		Strep. Fecalis	+	—	+
		Staph. Pyog. Aureus	+	—	+
174 "	24 "	Strep. Fecalis		—	+
		Staph. Pyog. Aureus	—	—	+
225 "	24 "	Staph. Pyog. Aureus	+	—	—
247 "	24 "	Staph. Pyog. Aureus	—	—	—

upon bacterial life depends directly on the amount of moisture and dust in the air.

Smoke, in contributing very great numbers of minute particles to the air adds to the conditions favoring fogs and clouds. Smoke, fogs, and clouds, all absorb more or less, the blue, the violet, and ultra-violet rays of the sunlight. This is well seen in the familiar red sun of a smoky atmosphere. These particular rays, which are absorbed, give the important bactericidal action to the sunlight. Most of the above facts have been amply proved by other experiments and it was not considered advisable to repeat them. We have, however, made a few observations on the protective action of soot for bacteria.

The technique of our experiments was briefly as follows: Agar-agar, well seeded with the test organism, was poured into petri dishes. Soot was sifted over one half

of the cover of the petri dish while the other half remained free. These plates were then exposed to the sunlight for definite periods, then incubated and the results read.

A number of plates, seeded with Staphylococcus Aureus, were exposed to sunlight for varying periods every day for two weeks. The results obtained are shown in Table IX. Notwithstanding the irregularity of these results the protection, afforded by the soot in the air and clouds against the action of the sun's rays, is, I believe, clearly shown.

There are a number of very interesting questions which arise as a result of these experiments. It has been shown that soot in contact with bacteria has very decided bactericidal properties. These properties are also demonstrated in the soluble content of the soot. The soot particles from the air as they fell on our plates were generally sterile. This may be due to the solution of the bactericidal substances of the soot by the moisture on our plates, with the consequent destruction of any bacteria adherent to the soot. Or the moisture condensing around the soot as it does in the formation of fogs and clouds, may have acted in the same way before it was collected on our plates. The third possibility is that the majority of the soot particles never came in contact with bacteria after leaving the chimney, at which time they were, of course, bacteria free.

That this disinfectant substance requires moisture in order to have its most powerful effect is well shown in the drying experiments where the organisms treated with soot, while still moist, succumbed very much sooner than the others. There is also the possibility that the soot absorbs moisture from the bacteria and hastens thereby its death by thorough drying. This was suggested in the experiment in which dried organisms were buried in soot and frequently killed off earlier than in the control.

TABLE VII.

Time of Exposure	Incubation Period	Influence of Soot on B. Diphtheriæ and Yeast (Saccharomyces).			
		Culture	Control. Dipped in Broth. then Dried	Cover Glass I. Dipped in Soot while Moist. Dried	Cover Glass II. Dried as in Control. Buried in Soot
3 days	48 hours	B. Diphtheriæ	+	—	
		Yeast	+	+	
	72 "	B. Diphtheriæ	+	+	
		Yeast	+	+	
7 "	24 "	B. Diphtheriæ	+	—	+
		Yeast	—	—	—
	48 "	B. Diphtheriæ	+	—	+
		Yeast	+	+	+
	72 "	B. Diphtheriæ	+	+	+
		Yeast	+	+	+
16 "	48 "	B. Diphtheriæ	+	—	+
		Yeast	—	+	+
	72 "	B. Diphtheriæ	+	+	+
		Yeast	—	+	+
27 "	72 "	B. Diphtheriæ	+	—	+
		Yeast	—	+	—
38 "	48 "	B. Diphtheriæ	+	—	+
	5 days	B. Diphtheriæ	+	+	+
41 "	48 hours	B. Diphtheriæ	+	—	+
		Yeast	—	+	—
77 "	72 "	B. Diphtheriæ	—	—	—
		Yeast	—	—	—

That the conditions, similar to those of our experiments, are to be found in every smoky city, will be evident to any one who has noticed the black, smeary deposit of soot on damp days where the concentration of soluble substances from the soot in crevices and corners must be very high. We have found, as others have demonstrated, that the effect of soot in fogs and clouds in diminishing the action of the run's rays on bacteria, is quite definite. The relative importance of the protective qualities of soot against sunlight to the bactericidal effect of the constituents of soot remains an open question.

There are, therefore, two divergent results brought about by the presence of soot in our atmosphere and upon the earth's surface. One of these is beneficial and the other harmful to the life of vegetable micro-organisms, and from the bacteriological and hygienic point of view may serve as a direct aid in propagating or preventing the spread of infectious disease.

TABLE VIII.

Organism Tested.	Inhibition of Solar Bactericidal Activity.			
	Time of Exposure	Incubation	Soot Covered Half.	Unprotected Half.
Strep. Fecalis	5 mins.	24 hrs.	Few colonies	None
	5 "	48 "	Many "	Many colonies
	15 "	48 "	Few "	No growth
	30 "	48 "	Few "	Many colonies
	45 "	48 "	Few "	Many "
	45 "	48 "	Many "	Few "
	120 "	48 "	Many "	Few "
B. Indicus	10 "	48 "	Many "	Many "
Staph. Aureus	10 "	48 "	Many "	Many "
	30 "	48 "	Many "	Many "
	45 "	48 "	Many "	Few "
	75 "	48 "	No "	No "
B. Mesentericus	15 "	48 "	Few "	Few "
	30 "	48 "	Few "	Few "
	45 "	48 "	Few "	Few "
	60 "	48 "	Few "	Few "
	75 "	48 "	Few "	Few "
	180 "	48 "	Few "	Few "

General Conclusions.

1. Soot has a definite bactericidal action on bacteria, due either to the absorption of moisture from the organisms or more probably, to the action of its contained germicidal acids and phenols.

2. Soot as it exists in the air does not form a favorable nidus for the collection and distribution of bacteria.

3. Broth and other fluids treated with soot have conferred upon them a decided germicidal power.

TABLE IX.

(Inhibition of Solar Bactericidal Activity by Smoke. Test Organism Staphylococcus Pyogenes Aureus.)

	Sun.	Clouds.	Smoke.	Result.	Note.
1	Bright		Clouds low.	Killed 1 hr.	
2	Dull	Present.	Clouds passing over sun.	Slight difference in 1 hr.	
3	Bright	Passing across sun.	None.	Killed 1 hr.	24 hr. incub.
4	Bright	Same.	"	Lessened in 15 and 30 mins. in proportion.	
5	Hidden, dull	Snowing in morning. Present.	"	Killed in 1½ hrs.	
6	Bright	Thin and white.	Around horizon.	Not killed in 1 hr., lessened.	
7	Clear	—	Haze around horizon.	Same.	
8	Bright and clear	Very few.	—	35 mins., much lessened; 1 hr., almost all killed.	
9	Bright and variable ..	Cloudy.	—	Not killed in 1 hr.	
10	Bright	None.	Much, low down.	Not killed in 1 hr.	Around edge.
11	Dull, foggy	Foggy.	—	Little change in 1½ hrs.	
12	Dull	Many, raining.	Much.	Almost all killed in 1½ hrs.	
13	Variable, free, dull	Variable.	—	Little change 1¾ hrs.	
14	Bright	None.	Haze.	Killed in 1 hr.	

4. This germicidal action is due not only to the acids contained in the soot but also to some other agent, probably some of the phenols.

5. Soot, as it occurs in smoke, clouds, fogs, and as a non-transparent covering for our streets and houses, protect micro-organisms from the destructive action of the sunlight.

I wish to express my thanks to Mr. C. H. Marcy for his valuable assistance in the early part of the work, more

especially in the study of the bacteriology of the air of Pittsburgh. I wish also to thank Dr. O. Klotz for many suggestions and Mr. Benner for the samples of soot and the chemical analysis of the same.

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Some Histological Evidences of the Disease Importance of Pulmonary Anthracosis*

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The histological evidences as to the disease importance of anthracosis of the lungs, as set forth in this paper, are the results of work done by the author in an attempt to determine whether or not extensive deposits of dust and coal pigment within the body tissues have or have not any "real disease" significance. The problem as originally planned included a study of all of the microscopic effects of smoke and soot upon the body as a whole. Such a piece of work has been impossible in the time at our disposal so that in the present paper we shall deal only with the microscopic effects of smoke and soot, as observed upon the air passages and lungs, which are the chief portals of entry for these substances into the body. We have also included a consideration of the association of the resultant pulmonary lesions with those of tuberculosis and pneumonia.

The paper naturally divides itself into three parts, and for the sake of clearness these will be discussed under the headings of: I. The anthracotic process; II. The association of anthracosis and tuberculosis; and III. The association of anthracosis and pneumonia.

In the use of the term anthracosis in this report it must be understood that it refers only to the fairly well

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advanced stages of the process, as will subsequently be described.

The tissues studied were obtained in part from the surgical and autopsy materials of the Department of Pathology of the University of Pittsburgh, and from the Mercy Hospital, and in part from experimentally produced lesions in animals.

I. The anthracotic process.—Anthracosis is a term applied to a condition in which carbon particles of extraneous origin are deposited in the tissues or organs. It has been described as occurring in the lungs, spleen, liver, intestinal tract, and certain sets of lymph nodes, and is always accompanied by more or less fibrosis on the part of the tissues in which it is found. The most common site for anthracosis is in the lungs, and in individuals who work or live in smoky, sooty atmospheres; it often reaches a marked degree of development.

The fine particles seem to gain entrance into the lung substance by way of the air passages, and it has been stated by some that the mucous membranes of the nose, mouth, pharynx, larynx, trachea, bronchi, and bronchioles contribute largely to the taking in of the pigment, but our observations tend to show that in this community (Pittsburgh), at least, such is not the case. In the nasal cavities, the vibrissæ, and turbinates collect a great deal of carbon, which is subsequently removed by the secretions, for in the examination of nasal polypi and strips of turbinate mucosa removed at operations we have never seen a single example of free pigment or pigment bearing cells beneath the epithelial layer. Maclachlan[1] in his paper on "Tonsilitis" in which he reported a histological study of three hundred and fifty pairs of tonsils found only one example of a carbon pigment bearing cell in that structure, and about as many more tonsils and adenoids have since been examined without finding another instance. In the air passages below the larynx, pigment bearing cells have frequently been observed, but these were either free in the lumina or were surrounded by bits of mucus and other

cells and were not found penetrating the epithelial layers. In abscesses of bronchi, both the abscess contents and remaining parts of the mucosa have been seen to contain pigment bearing cells, though one could not say that any of these were definitely passing into the tissues. Moreover, our contention is supported by the following two experiments:

Experiment I.—For twenty minutes daily a young guinea-pig was placed in a box through which a dense black smoke was made to pass. The smoke was generated by burning xylol and entered the box through a funnel. After each exposure the animal showed a profuse nasal secretion and sneezed repeatedly. His furry coat was completely blackened. At the end of ten days he was killed with chloroform and autopsied. Macroscopic description: The gross findings of soot deposit were entirely limited to the blackened nasal mucosa, which was especially marked over the anteriar portions of the turbinates. Microscopic description: Sections showed soot particles adherent over the epithelium of the nasal mucosa. There was no evidence of pigment phagocytosis. (Note.—Nothwithstanding the fact that three guinea-pigs with early spontaneous anthracosis have come under our notice we failed in our attempts to reproduce the condition experimentally, apparently on account of the efficient way in which the intricately arranged turbinates protected the air passages beyond them.)

Experiment II. A white rabbit was given sixty inhalations in eighty-seven days of finely powdered lamp black in the following way: The nose piece of a powder insufflator was placed in the animal's mouth and the lamp black was forced in under pressure. At first the inhalations were given every two or three days, but later the treatment was carried out daily. The animal became very much emaciated and died. The autopsy was performed while the tissues were still warm. Macroscopic description: All of the mucous membranes of the mouth, pharynx, esophagus, stomach, larynx, trachea, and bronchi were coated or crusted with black pigment. Many of the lesser bronchi were completely plugged with masses of lamp black so that the foci of lung beyond them were devoid of air and in a stage of collapse. A few fine black granules were seen in the lung tissue. Microscopic description: In no part of the upper air passages was the phagocytosis of pigment observed. No pigment was seen in or beneath the epithelial layers of the bronchi, though some of them contained sufficiently large masses of pigment in their lumina to cause a flattening of the epithelial lining cells. In the alveoli many pigment phagocytes were seen (Fig. 5), and these cells were especially numerous in the atelectatic areas; some of them had already penetrated into the spaces of the alveolar walls, but as yet none had reached the perivascular, peribronchial, or subpleural lymphatics. The peribronchial lymphoid tissue was also free from pigment. The carbon pigment cells were large and round and were so completely filled with granules that their identity was obscured.

It will be seen by these two experiments that although we were able to bring an abundance of carbon pig-

ment in direct contact with the epithelial linings of the oral cavity and upper air passages we were unable to obtain any evidences of phagocytosis of such pigment in any of these structures. Coupling these results with our negatice findings in the surgical and autopsy materials cited above, we feel justified in concluding that the amount of pigment phagocytosis in the air passages above the lung alveoli must be a negligible quantity.

As our studies on the anthracotic process have to do largely with the lung alveolus and with the lymphatics of the lung a hasty review of our knowledge of these structures seems advisable at this point.

The alveoli, or air sacs, are minute cuboidal or spheroidal cavities which open directly into the small bronchioles through the infundibuli. The cavities are lined by a single layer of very flat pavement cells, which rest on a very thin basement membrane. Small openings called stomata sometimes connect one alveolus with its neighbors. The walls contain both smooth muscle and elastic tissue and are exceedingly vascular. The vessels are capillaries with definite endothelial walls, and they form a network completely surrounding the alveoli.

The lymphatics have their beginnings as small intercellular spaces in the alveolar walls. These connect with larger lymph spaces in the interlobular septa, which then empty into definite channels also having endothelial linings. These latter channels are found in three sets which are called, according to their location, perivascular, peribronchial, and subpleural. The larger channels have valves and foci of lymphoid tissue distributed along their courses. They all terminate finally in the peribronchial nodes.[2]

Most text books on general pathology discuss the process of anthracosis, but they do not enter into a description of the steps by which the condition develops. We have based our conception on the study of a great many lungs in the various stages of the anthracotic condition, and a description of the appearances of lungs in these var-

ious stages will serve to explain how we reach our conclusions.

The finding of free carbon particles in the alveolar spaces was unusual, though in some of the very advanced cases black pigment masses filled some of the alveoli in such a way as to resemble a complete cast. In the early stages of the anthracotic process, the condition was manifested only by the presence within the air sacs of large round mononuclear phagocytes filled with carbon pigment, while in the slightly more advanced stages these cells were not only present in the alveoli but were also found in the interalveolar lymph spaces, in lymphatics of the interlobular septa, in those about the vessels, and beneath the pleura, and in those of the lower layers of the bronchial mucosæ. A little later these cells were found gathered in nests of considerable size, and many of them were seen to be compressed into spindles so that only the elongated nests of granules were visible. The very advanced conditions consisted only of a quantitative increase in all of the features mentioned above and if one examines a lung in a late stage of anthracosis, such as we have commonly observed in Pittsburgh, the following points will be noted: The deep layers of the bronchial mucosa may or may not show pigment bearing cells, and when they are present they are generally grouped about the small mucosal vessels. The alveoli contain pigment casts, pigment bearing phagocytes and rarely free pigment particles. The phagocytes are found in the lymph spaces between the alveoli, about the vessels, in the septa, and beneath the pleura, and those about the vessels are so numerous as to form rosette-like nodules consisting of alternate layers of pigment cells and of connective tissue trabeculæ (Figs. 1 and 7). The amount of connective tissue may be out of proportion to the number of pigment cells present. The striking point in the whole picture is the extensive plugging and obliteration of the small and medium sized lymphatics and the compression of the large

ones. In the pleura and in the peribronchial lymph nodes the picture is a similar one, and in the latter the lymphoid tissue is often completely replaced by a scar tissue, the meshes of which are full of pigment spindles. By following the findings from stage to stage, the process appears to consist in the taking up of the carbon pigment by cells in the lung alveoli and its transportation through the lymph spaces and channels to the peribronchial lymph nodes. During the process of transportation many of the pigment cells appear to be caught in the lymph spaces causing a backing up of similar cells in the spaces behind them. Here the cells seem to act as irritants and cause the proliferation of connective tissue, which holds them firmly. The nodules appear to be formed by the alternate blocking of small perivascular lymph spaces by pigment bearing cells and the formation of new spaces about the outside of the occluded ones. The new spaces then seem to become obstructed by the pigment cells in a similar way and so on until the concentric nodular anthracotic rosette is formed. The cells nearest the center are always more flattened and spindle shaped than those in the periphery. The continuation of the process over a long period of time leads gradually to a very severe embarrassment of the lymphatic drainage of the lung. It seems well to observe here that the separation of anthracosis by some authors into diffuse and nodular forms is one of degree only, as the condition which is diffuse in the early stages becomes nodular in the later forms.

Four very interesting questions arise in connection with the anthracotic process which we have up to the present purposely omitted from the discussion, because they seemed to be sufficiently important to deserve consideration under separate headings.

1. The question of the part played by the alveolar epithelium in the phagocytosis of pigment. Several authors state that the epithelial cells of the lung take up anthracotic pigment and that the pigment bearing cell is merely a desquamated alveolar lining cell. The author

devised a combined staining method based on Heidenhain's hematoxylin as a nuclear stain, in combination with Mallory's aniline blue connective tissue method, which brought out the epithelial lining cells of the alveoli as clearly defined cells with red protoplasm and dark brown nuclei, resting upon a pale blue basement membrane. This stain was applied to sections from two hundred anthracotic lungs, and no pigment granules were found in the attached epithelial cells (Figs. 3, 4). After they had become desquamated it was difficult to identify the epithelium from other mononuclear cells present, except in certain instances where the desquamation occurred in strips of several cells, attached end to end. In none of these instances were epithelial cells seen to contain pigment.

While not wishing to state definitely that epithelial cells cannot and do not take up pigment under some conditions we have no hesitation in saying that it is not the usual procedure and that we must look to other sources for the identity of the common pigment phagocyte.

2. Concerning the question of the identity of the pigment phagocyte. Beitzke[3] says that the pigment phagocyte is sometimes derived from the alveolar epithelium and at others is a wandering mononuclear white cell from the blood. Other authors have described them as endothelial leucocytes, those cells formerly called transitional and large mononuclear leucocytes which have been shown to come from the endothelial lining of the blood and lymph spaces.[4] We were able to get no specific stain to definitely settle this point. However, the pigment phagocyte observed in the alveolus and the endothelial leucocyte have many points in common. They are indentical in size and appearance, they are both phagocytic, for blood pigment, as well as coal pigment, they both take up all kinds of cells and cellular debris and lastly we will show—later that the pigment phagocyte and the early cell of the tubercle, which we believe to be an endothelial cell, is one and the same cell.

By injecting pigment, in the form of Higgin's India ink, diluted one in five with normal saline we have attempted to determine the indentity of the cells which acted as phagocytes.

Experiment III.—Guinea-pig 2. Two cubic centimeters of dilute India ink was injected beneath the scapula at 5 P. M. The animal was found dead at 8:30 A. M. on the following morning, and presented the appearance of having died some hours before. Macroscopic description: The subscapular region was found much blackened and the neighboring lymphatics were deeply injected with black pigment. Microscopic description: In the sections many polymorphonuclear leucocytes were present in the region and a few of them contained a scant number of granules of pigment. A relatively few endothelial leucocytes were present, but all of them contained abundant granules.

Experiment IV. A similar dilute ink injection was made into the interstitial tissues of the abdominal walls of a guinea-pig. The animal was autopsied at the end of twenty-four hours. Macroscopic description: There was present in the tissues of the abdominal wall a localized nodule of swollen, edematous, and blackened tissue from which both smears and sections were made. Microscopic description: Both smears and sections showed a considerable number of endothelial leucocytes, and all of them contained a great number of pigment granules. There was a very marked polymorphonuclear leucocytic exudate present, but only occasional leucocytes were found containing pigment granules (Fig. 6).

Experiment V.—This experiment was similar to the preceding, save that the injection was repeated at the end of twenty-four hours. The animal was examined at the end of forty-eight hours. Macroscopic description: The gross appearance of the abdominal wall was similar to that in the preceding experiment. Microscopic description: A severe local endothelial leucocytosis was shown in the sections and most of these cells contained pigment. Many polymorphonuclear leucocytes were also present, but the phagocytosis of the pigment by these cells was insignificant.

It appears from these experments that the polynuclear leucocytes may take up pigment, but that their action is transient and unimportant, while the observations point to the endothelial leucocyte as the chief pigment phagocyte of the body.

3. The length of time during which the enclosed pigment remains intracellular is very important. As we have described above, the pigment bearing cells often become caught in the lymph spaces and when they have been surrounded by scar tissue appear simply as pigment spindles and look like nests of free granules, or as if they were incorporated in spindle shaped connective tissue cells

(Fig. 7). In acute inflammation of the lung, and more particularly in edema, the spindles again assume a more or less round or oval form (Fig. 8), suggesting that the spindle shape is due entirely to the pressure of the scar tissue. In two experiments we were able to reproduce the condition.

Experiment VI.—A small amount of dilute India ink was injected interstitially into the ear of a rabbit. At the end of twenty-six days sections were made. Almost all of the pigment had been taken up and was found in the form of spindles firmly fixed between strands of connective tissue (Fig. 9).

Experiment VII.—The ear of another rabbit was treated in a similar way. After forty days the ear was dipped into water at 60° C. for three minutes. At the end of fifteen hours a very extensive edema of the ear had developed and the animal was brought to autopsy. Sections showed a very extensive interstitial serous-exudate, without any cellular elements, to separate the strands of connective tissue very widely. Almost all of the pigment was found to be present in cells which were of the large round type (Fig. 10).

In some processes within the lung, such as abscess, gangrene, the various granulomata, and tumors, which are accompanied by necrosis, the anthracotic pigment is found extracellular and is seen widely distributed as free granules. These granules sometimes remain free in caseous areas, or in scar tissue, or they may again be engulfed by large mononuclear phagocytes. From our own observations we feel justified in saying that carbon pigment once taken up by the cells remains intracellular indefinitely, unless freed by some process producing general necrosis of the tissues.

4. How long do phagocytic cells remain free in the alveoli? There is at present no accurate means of determining the length of time during which a cell may remain free in the alveolus, though there are several points which indicate that this is longer than is generally supposed. One may observe many cells in the lung alveoli which are only partially filled with pigment, but to find such a one in the intra-alveolar lymph spaces is quite unusual. This suggests that the phagocytic cells are generally pretty well loaded when they leave the alveoli.

In pneumonia and edema of the lung where individuals have been confined to the hospital for some time and presumably not inhaling very much pigment, the alveoli often contain numerous pigment bearing phagocytes. The almost constant presence in the alveolar spaces of "Herzfehler Zellen" in brown induration of the lung is hardly a terminal condition, and establishes further evidence that phagocytic cells may remain free in the alveoli for a considerable length of time. In Experiment II. we found that although the soot inhalations had been carried on for eighty-seven days, pigment bearing cells were found only in the alveoli and inter-alveolar spaces and there was no evidence that any had migrated as far as the large lymphatics. All of these points seem to indicate that the phagocytic cells are not transient scavengers, but in a more leisurely manner gather their pigment-load and transport it to the tissue spaces.

Summarizing the foregoing work we conclude:

1. The quantity of pigment taken up by the upper air passages is a negligle one.

2. The lining cells of the lung alveoli take little or no active part in the phagocytosis of carbon pigment.

3. The process consists in the phagocytosis of the pigment within the lung alveolus by a cell, which is probably an endothelial leucocyte. This cell then passes into the pulmonary lymphatics where it sometimes lodges and becomes surrounded by connective tissue. The pigment remains intracellular until acted upon by some process producing a local necrosis of the tissues.

4. The importance of the sequence of the process lies in the fact that the lymphatics of the lung become obliterated either mechanically or by fibrosis.

II. The association of anthracosis and tuberculosis.—Pulmonary tuberculosis in adult individuals in Pittsburgh is constantly associated with more or less anthracosis, so that ample opportunity was afforded for the study of the effect of the one upon the other. The important lesion of tuberculosis is the tuberculous granuloma

or "tubercle," and the following discussion is confined to a consideration of the related lesions of this characteristic tuberculous lesion, and anthracosis.

The present day knowledge of the histogenesis of the tubercle is the result of the accumulated work of more than a generation of pathologists. Point by point has been added year by year, and credit cannot be given to any single individual or group of individuals, and more especially is this true for the reason that our facts are still deficient in certain details. The names of Baumgarten[5] working in Germany and of Borrell[6] in France, however, stand out prominently among the founders of the experimental studies, to which we owe so much. The formation of the tubercle as we understand it at present, seems, in general, to occur in the following way:

When tubercle bacilli enter the smaller vessels or lymph spaces they are shortly incorporated by the cells° lining these structures. In both blood vessels and lymph spaces the process appears the same so that the description of the former will suffice. The cells which have taken up the tubercle bacilli undergo rapid proliferation and develop a nest of proliferated endothelial cells which tends to fill the vessel, obliterate it, cut off the nutrient supply to the nest, and leave it an extra-vascular structure. The endothelial cells have by this time changed their morphology and somewhat resemble epithelial cells, for which reason they have long been known as "epithelioid" cells. About this time a few polymorphonuclear leucocytes may frequently be seen in the margins of the structure, but, in the later stages, lymphocytes alone are present. The next change which is usually observed is the appearance, near the center of the nest, of a multinucleated or giant cell, which was described by Langhans in his early studies on tuberculosis and to which his name has been given. That the Langhans' giant cell is the product of the endothelial cell seems now to be unquestionable, but a considerable dispute still exists as to whether it arises by a fusion of the endothelial cells or by a division of the nucleus

without a multiplication of the cell. Caseation necrosis is next seen near the center of the nest and commonly first manifests itself in the center of the giant cell. With the appearance of caseation there is not uncommonly a proliferation of connective tissue about the margin which is an attempt on the part of the tissues to encapsulate the lesion. This completes the structure of the miliary tubercle (Fig. 15). Complete encapsulation and healing may follow with more or less absorption of the necrotic matter by the tissues,[p] or the deposit of calcium salts within the caseated areas. On the other hand a local or general spread of the tuberculous process may follow. A certain amount of local invasion from the original tubercle may take place by direct extension leading to the development of numerous closely aggregated and fused tubercles. The lesion thus produced is known as a conglomerate tubercle. A more extensive local spread, even to the involvement of an entire organ, often takes place by way of the anastomosing lymph spaces.

Recently, considerable evidence has been advanced to show that the so-called epithelioid cells are at all times endothelial cells, and if this is true the term "epithelioid," which is somewhat confusing, should be discontinued. Mallory has called attention to the constant involvement of endothelial cells in the earliest recognizable lesions of tubrculosis, and has shown that no fibrils are demonstrable by stains in the tubercles until the stage of encapsulation is reached, at which time fibrils appear in conjunction with the proliferating connective tissue cells in the outer border. Since endothelial cells are not known to produce fibrils, the evidence is in favor of the essential cell of the tubercle being endothelial in character. Bowman, Winternitz, and Evans have shown experimentally that tubercles may be developed in the liver from the Kupffer stellate cells, which are also considered as endothelial cells. By first inducing a vital staining of these cells in animals by injecting trypan blue into the circulation, then inoculating the same animal with tubercle bacilli, they

were able to follow the formation of tubercles by the stained cells. I have also induced the development of tubercles experimentally, the essential cells of which were phagacytie both for pigment granules and the tubercle bacillus (Experiments VIII., and IX., and X., and Figs. 17, 18, and 19), and if we were right in concluding that the endothelial cell is the general pigment phagocyte of the body, we have another link in the chain which indentifies the "epithelioid" as an endothelial cell.

As to the nature of the Langhans' giant cell we have, in several instances, observed multinucleated cells containing both pigment granules and tubercle bacilli. This would indicate that the cells exhibiting the phagocytic properties to foreign particles and tubercle bacilli were of the same origin and that the giant cells were but a morphological modification of these. As to the way in which the phenomenon of multinucleation occurs we have no conclusive additional evidence. An experiment was planned by which it was hoped to discover a constant ratio between the amount of pigment taken up and the number of nuclei present in the giant cell. The experiment failed, firstly, because time was not allowed for complete phagocytosis of the pigment before the tubercle bacilli were introduced and, secondly, because the amount of pigment used was so great as to completely obscure many of the nuclei in the cells. The experiment though unsuccessful seems worthy of repetition.

Lesions illustrating the association of the various stages of tubercle formation with all degrees of anthracosis were found in the materials secured from the autopsies and the following interesting observations were made: (1) Examples of early tubercles were found which consisted of simple nests of endothelial cells, some of which contained black pigment granules though they differed apparently in no other way (Fig. 16). (2) Pigment granules were found in many of the giant cells, and when caseation necrosis was also present in these cells the nuclei were found arranged in the periphery with the

pigment granules grouped in circles about them (Fig. 20). (3) In tubercles where caseation was advanced much of the pigment was found to have been liberated and occurred either as free granules diffusely distributed throughout the necrotic foci or, as was more often the case, gathered in the margins of the caseous areas where it was found undergoing a second phagocytosis by endothelial cells (Fig. 21). (4) Many partially and completely encapsulated tubercles were seen with great numbers of pigment spindles caught in the meshes of the capsules, and in these instances the connective tissue was unusually abundant. Obliteration of the neighboring perivascular lymph spaces by anthracotic fibrosis was a common additional finding in some of these lesions.

The number of cases examined was too small to allow the drawing of a general conclusion, but it seemed that there was less local spread and more extensive fibrosis in this latter type with anthracosis than is usual in ordinary pulmonary tuberculosis. It further seemed that the presence of pigment within the endothelial cells did not interfere with their development of typical tubercles (Experiments VIII., IX., and X.).

Experiment VIII.—Two cubic centimeters of a very dilute suspension of India ink was shaken up in normal salt solution with two loops of bacillus tuberculosis bovinus (kindly furnished by Dr. W. L. Holman) and was injected into the deep muscles of the thigh. After twenty-four days the animal was killed with chloroform and autopsied. Macroscopic description: Indefinite grayish-black tubercle-like nodules were found among the muscle fibers, and some of the intermuscular lymph spaces appeared as blackened lines. There was no evidence of involvement of the inguinal nodes, nor of the other organs or tissues of the body. Microscopic description: Many early tubercles were seen in the process of formation and the cells composing them often contained black pigment granules (Fig. 17). Tubercle bacilli and these pigment granules were repeatedly found in the same cells. Relatively few multinucleated cells were seen, but in some of them bacilli and pigment granules were found together. Practically no fibrous proliferation was present about the lesions and the cells did not show any kind of fibrils when special stains were applied.

Experiment IX.—One cubic centimeter of a I in 5 suspension of India ink in normal saline was shaken up with two loops of bovine tubercle bacilli and injected underneath the scapula of a rabbit. Ten days later inhalations of soot similar to those used in Experiment II were begun. These were carried out about every five days

and about fifteen inhalations were given. After seventy-four days the animal died from general tuberculosis. Macroscopic description: A large caseous mass about 4 centimeters in diameter,[p] near the center of which was a small black nodule was found beneath the scapula. The lungs, liver, spleen, and kidneys showed very advanced caseous tuberculous lesions. A few rather indefinite black granules appeared about the margins of the lung tubercles. Microscopic description: The lungs alone are of interest in this experiment. They contained all stages of tuberculous lesions, and a few fine pigment granules were observed in some of the cells forming the tubercle. Two vascular lesions were of interest because they showed direct extensions of early tubercles into the lumina of vessels without causing rupture of the walls. The subscapular lesion was in a very advanced stage of caseation necrosis and was valueless for study.

Experiment X.—Injections as carried out in Experiment VIII. were made into the interstitial tissue of a rabbit's ear. The animal was brought to autopsy at the end of twenty-six days. Macroscopic description: The ear showed one large diffuse black area involving approximately one-half of the ear. The tissues were somewhat thickened and contained three large and several small grayish-black nodules. At the base of the ear was found an enlarged and blackened lymph node. Microscopic description: Sections of the ear and lymph node both demonstrated the presence of early tubercles, with black pigment granules in the cells of the tubercle, and in both instances tubercle bacilli and pigment granules were found in the same cells (Fig. 19).

In all three of these experiments we were able to induce miliary tubercles,[p] formed by cells which were filled with pigment granules. This indicated that the presence of pigment in the specific cells did not exert any inhibitory influence to the development of tubercles. By demonstrating pigment granules and bacilli in the same cells of the tubercle, we were able to show that a single cell may actively phagocyte both materials. In other words, the essential cell of the tubercle and the pigment phagocyte were found to be identical. Still more interesting was the finding in Experiment X. in which both the pigment phagocytes and tubercle forming cells were found in a neighboring lymph node, where tubercles were being formed by cells which contained pigment.

Summing up our observations on the associated lesions of anthracosis and tuberculosis we came to four conclusions:

1. The cell which takes the early active part in the formation of a tubercle is phagocytic for tubercle bacilli

and for pigment granules and is probably an endothelial cell.

2. The presence of pigment granules within these cells does not interfere with the cells taking part in the formation of a tubercle.

3. The presence of pigment-bearing cells in the connective tissue about tuberculous lesions acts as an additional stimulus to fibrosis and encapsulation.

4. The obliteration of the pulmonary lymph spaces in the anthracotic process is unfavorable for the local spread of tuberculosis, and aids in the localization of the condition.

III. The association of pneumonia and anthracosis.—With pneumonia the relation of anthracosis is a very different one. The process is one of acute inflammation wherein the alveoli, bronchioles, and often the smaller bronchi become filled with a fibrino-purulent exudate. Ordinarily this exudate remains in the alveoli for a relatively short time, usually from five to nine days, and then undergoes resolution. The process of resolution consists, firstly, in a softening and liquefaction of the exudate, which takes place through the autolytic action of the different elements, and is known as puriform softening, and secondly, in getting rid of the resulting debris. Much of the resolved exudate is coughed up, but the greater part of it passes back into the circulation by way of the lymph spaces and through the lymph nodes.[7] During resolution these spaces are found to be dilated and to contain fluid, fragments of fibrin and many types of exudative cells. Among these cells are numerous phagocytes containing other cells, cell debris, fibrin, and fat globules (Fig. 13). The contents of the sinuses of the lymph nodes is exactly the same (Fig. 12). It is evident that for the removal of this debris as well as for active phagocytosis comparatively large channels are necessary, and it is obvious that anything which may impede the passage through the lymphatics must interfere with the healing process. The mechanical blocking of the spaces forces the debris to find

other channels of exit, and the imperfect drainage leads to the accumulation of waste products which, in turn, may retard the activity of the proteolytic enzymes.

When for any reason resolution of pneumonia fails to take place the microscopic picture presents certain characteristics. The cellular elements of the exudate are not numerous and are often lymphocytic; the fibrin becomes contracted into firm hyaline, spindle, or fan-shaped masses which are bathed in fluid, and the alveolar wall appears thickened and edematous. At somewhat later periods these fibrinous masses occasionally undergo organization in a way comparable to the repair of a wound. Abscesses are also very common findings in pneumonic lungs where failure of resolution has occurred, and gangrene is also seen in some instances. Not only are such lungs unusually susceptible to secondary infection, but the actual presence of the undigested fibrin is claimed to be extremely toxic.

Our evidence of the effects of anthracotic conditions on pneumonia was obtained by a microscopic study of sixty-two cases of the disease. Of these, thirty-eight were lobar, twenty were of the bronchial type, four were hypostatic, and two were the end result of general septicemia.

Of the thirty-eight lobar pneumonias, nine, or nearly twenty-five per cent., were diagnosed "unresolved" at autopsy and two others presented microscopical evidences of the same condition. Two of the bronchial type contained much hyaline fibrin and abscesses, and one of the hypostatic variety showed advanced organization.

This unusually large percentage of failures in resolution suggested a careful study of the pulmonary lymph spaces in these cases. This was carried out as far as we were able in the sections. Our attention was mainly directed toward the large channels because the small lymph spaces were obviously involved in all of the cases, and also because a severe involvement of the larger lymphatics indicated an extensive participation of the smaller contributory vessels over a considerable area. We found the

large perivascular and subpleural lymph spaces closed or compressed in four cases by anthracotic fibrosis. Two cases presented a similar picture save that the amount of scar tissue seemed to be out of all proportion to the number of pigment cells. One instance was found where the lymph spaces were closed by scar tissue alone, and in two others there was no local evidence which could be construed as having anything to do with failure of resolution. The two remaining cases were pneumonias in which there were coexistent septicemias, and were omitted from consideration because the origin of the lung abscesses might have occurred as a part of the general process. Both of these lungs were examples of late stages of anthracosis. Our results, then, showed that in six of the nine cases of unresolved pneumonia the larger lymph channels were severely embarrassed by the anthracotic process.

The failure of resolution in pneumonia is commonly attributed to the low state of the general bodily condition, although Pratt[8] called attention to the frequency of delayed resolution in individuals who had been previously attacked, and attributed it to the fibrosis of the lymph spaces following the lymphangitis which occurs during resolution.

The results of the microscopic examination of the lymphatics in the total number of lobar pneumonias were as follows: Eighteen cases presented dilated lymph spaces filled with serous or sero-purulent exudate; five were closed by acute fibrino-purulent exudate, nine were practically obliterated by anthracosis; two were obliterated by scar tissue, and four were in the stage of resolution with large numbers of phagocytes in the lymph sinuses.

An analysis of these findings seems to indicate that during an attack of pneumonia in an otherwise normal lung the lymph vessels are generally engaged in an active exchange of fluids. Even in those instances where these channels are filled with a fibrino-purulent exudate this

exudate has a better chance of becoming liquefied and returning to the circulation than a similar exudate in the alveoli. So that even under these circumstances they would again be available for drainage.

The presence of the phagocytes in the channels and in the sinuses of the lymph nodes shows fairly conclusively that the lymphatics are important drains during the stages of resolution of pneumonia, and if these are closed the waste products of autolysis of the exudate must accumulate, and such an accumulation undoubtedly interferes with proper enzymatic action. In several of the above mentioned cases where the lymphatics were found to be closed, death occurred before the stage of resolution was reached. It is, of course, impossible to say that the presence of the anthracotic condition had any definite connection with the fatal result. Yet it is likely that the lymphatics in inflamed areas are just as important for the entrance of fresh fluids as for the exit of waste materials. It has been variously shown that the cultures of pneumococci obtained from pneumonic lungs after crises are less virulent than those made in the early stages, and this suggests some immune reaction against the organisms. If we are correct in the supposition that immune substances are the products of the entire body as well as of local origin, we must recognize the need of a constant influx of fresh fluid containing such immune products. It seems, then, that the closed lymph spaces may have had some effect even in this latter class of cases.

Our series although small seems to point toward a certain relation between "unresolved pneumonia" and anthracosis with chronic obliterating lymphangitis.

An interesting collateral finding, brought out by the newly devised staining method used in demonstrating alveolar epithelium, showed that desquamation of alveolar epithelium in pneumonia is inconstant and occurs only in some alveoli. Instances were observed in which the pneumonia had reached a stage of resolution and yet practically all of the alveolar epithelium was intact.

1. Any process which interferes with the free lymphatic drainage during pneumonia will delay resolution, both by actual mechanical obstruction to the migration of cells, and by aiding in the accumulation of waste products probably embarrassing enzymatic digestion of the exudate.

2. Anthracosis is an important process in the lung interferring with lymphatic drainage, and is a factor in causing delayed resolution.

Summarizing the various points indicating the disease importance of anthracosis which we have gathered from histological evidence we draw the following conclusions:

1. Moderate anthracosis in an otherwise normal lung is not in itself detrimental to health.

2. In tuberculosis and granulomatous conditions in which the reactions are chiefly centered in focal lesions of the tissues, the anthracotic condition is either entirely passive, or is active in assisting healing, in that it is an additional stimulus to fibrosis and encapsulation and in that it aids in the localization of the process through the obliteration of the lymph spaces.

3. In acute inflammatory conditions where the lymphatics are important for proper resolution, anthracosis becomes seriously detrimental, because of the obliteration of these spaces.

[I wish to express my thanks to Dr. Oskar Klotz for his very able advice during the preparation of this paper and to Mr. William Coburn for his efficient aid in carrying out the experimental work.]

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Description of Plates XIV-XVII

DESCRIPTION OF PLATES XIV-XVIII.

Plate XIV., Fig. 1.—Perivascular arrangement of nodular anthracosis.

Fig. 2.—Subpleural type of anthracosis.

Fig. 3.—Alveolus containing many pigment phagocytes and a pneumonic exudate. Note the alveolar epithelium swollen and free from pigment.

Fig. 4.—Alveolus containing pigment phagocytes with alveolar epithelium intact. Note one cell containing both pigment and a red blood corpuscle.

Plate XV., Fig. 5.—Experimental anthracosis. Pigment phagocytes in alveoli and inter-alveolar lymph spaces.

Fig. 6.—Injection of carbon pigment in abdominal wall. Pigment present in large round cells and in inter-cellular spaces. Polynuclears contain no pigment.

Fig. 7.—Spindle-like arrangement of pigment in perivascular anthracotic nodules.

Fig. 8.—Effect of edema on spindle-like pigment occlusions in perivascular anthracosis.

Plate XVI., Fig. 9.—Experimental fibrosis produced by the injection of India ink into a rabbit's ear.

Fig. 10.—Effect of artificially produced edema on rabbit's ear which had been treated in a similar way to that seen in the preceding figure.

Fig. 11.—Alveoli containing pneumonic exudate in stage of resolution. Note epithelial cells intact on alveolar walls.

Fig. 12.—Lymph spaces of peribronchial lymph node containing phagocytes from preceding figure.

Plate XVII., Fig. 13.—Perivascular lymph space filled with broken up fibrin and phagocytes from same case as preceding figure.

Fig. 14.—Perivascular lymph spaces completely obliterated by carbon pigment and fibrosis. From severe case of unresolved pneumonia.

Fig. 15.—Formation of early lung tubercle.

Fig. 16.—Early tubercles containing pigment bearing cells (human).

Fig. 17.—Experimental tubercle in rabbit's thigh. Pigment bearing cells actively forming the tubercle.

Plate XVIII., Fig. 18.—Oil immersion view of same tubercle. Cells contain both pigment granules and tubercle bacilli.

Fig. 19.—Tubercles containing pigment bearing cells in lymph node.

Fig. 20.—Arrangement of pigment in giant cells in late stage of tuberculosis.

Fig. 21.—Distribution of carbon pigment in the periphery of caseous tubercle.

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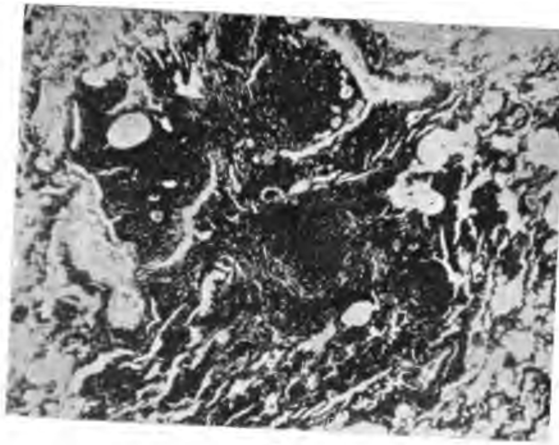

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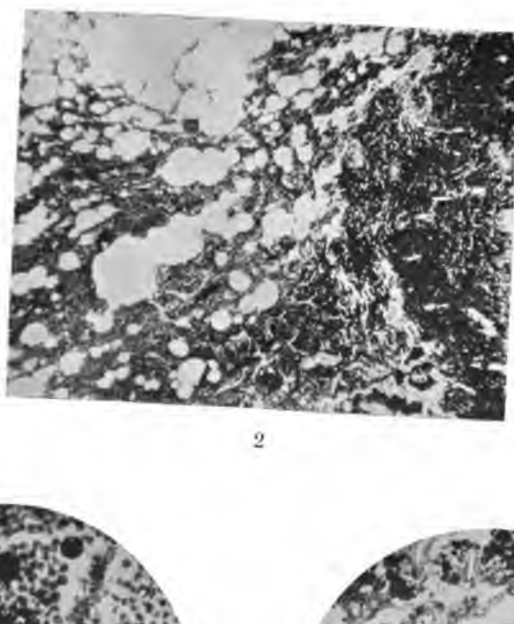

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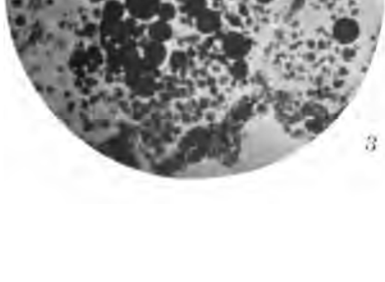

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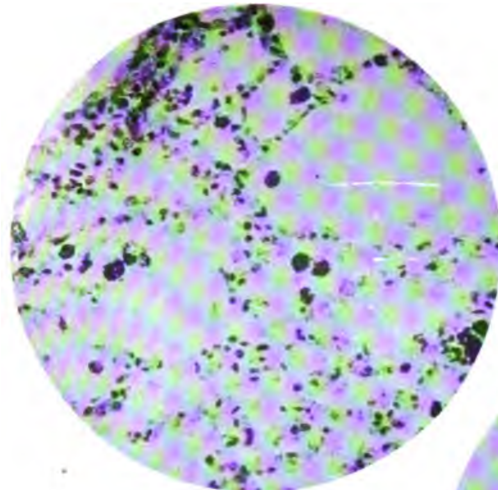

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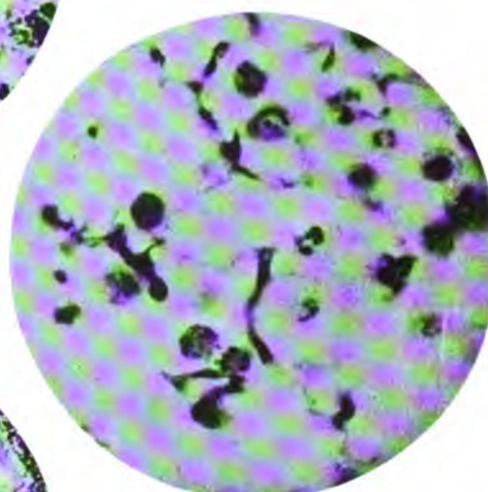

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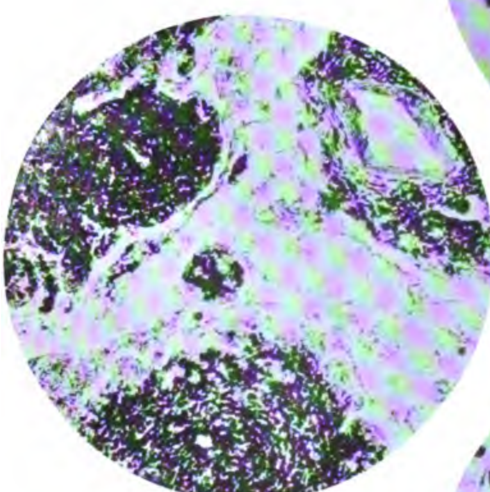

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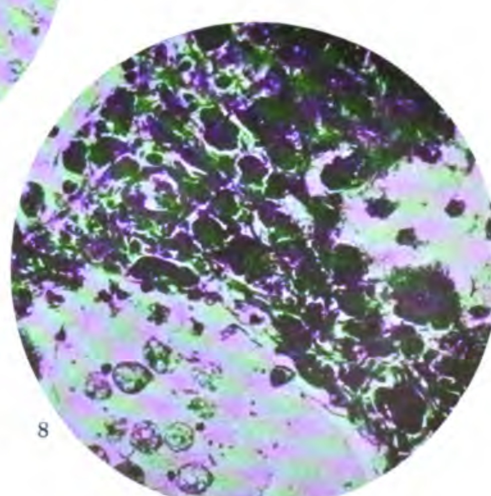

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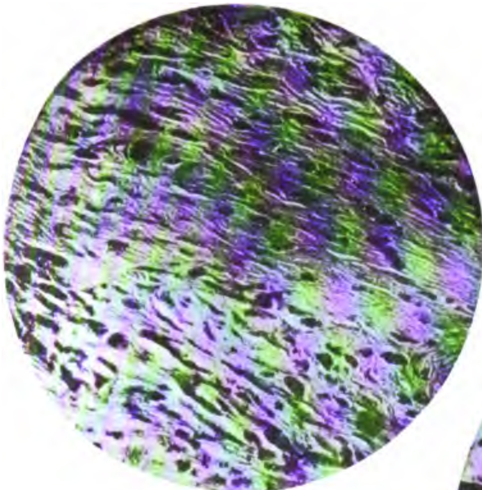

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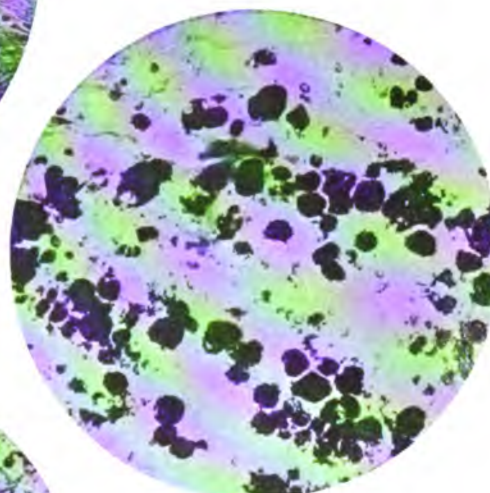

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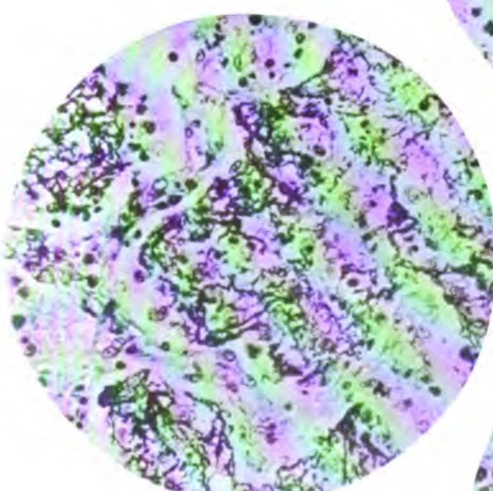

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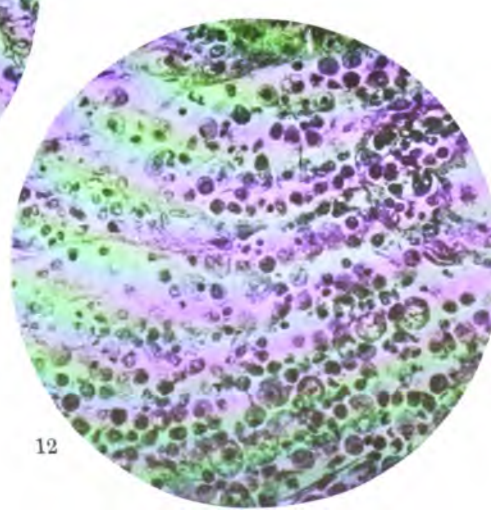

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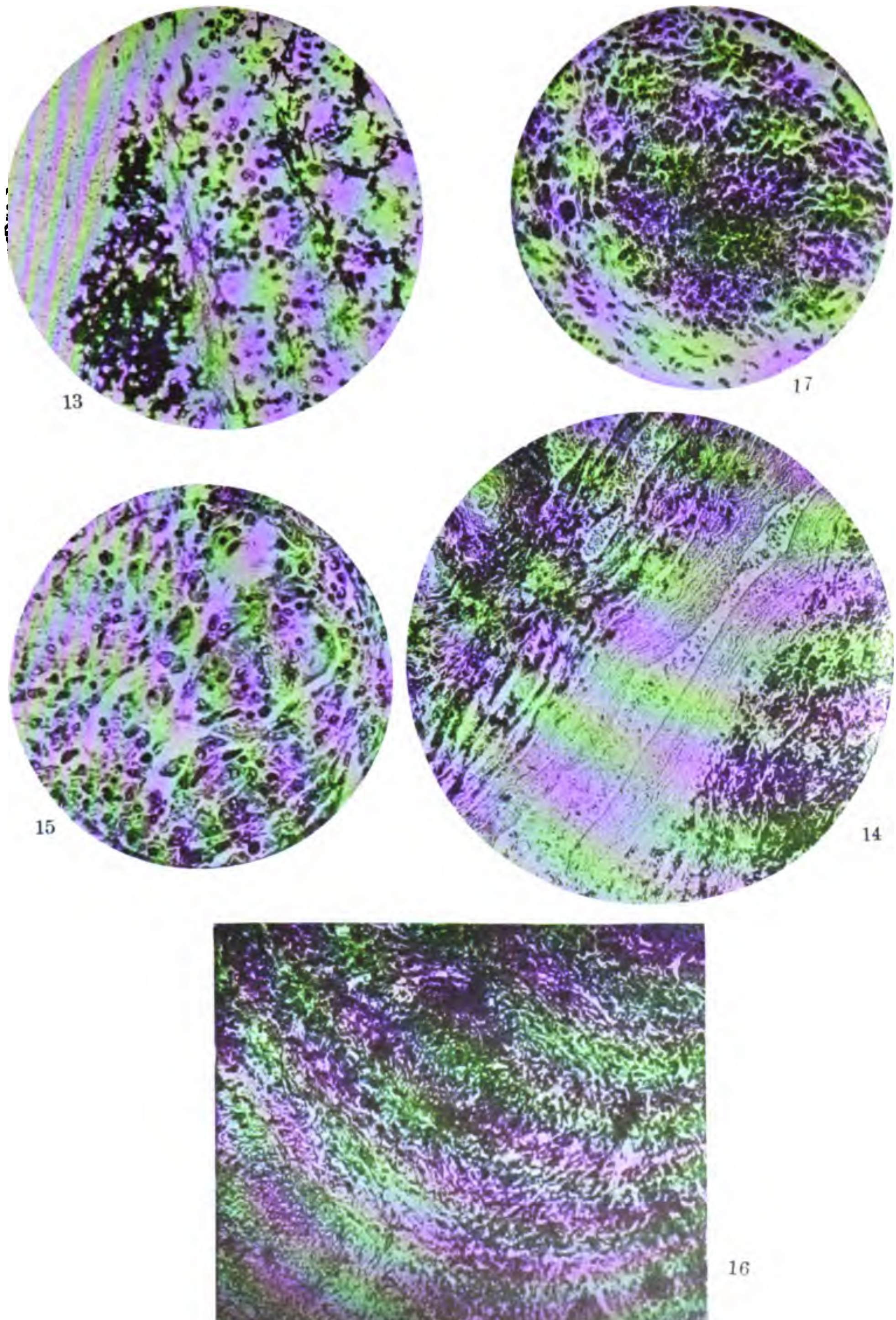

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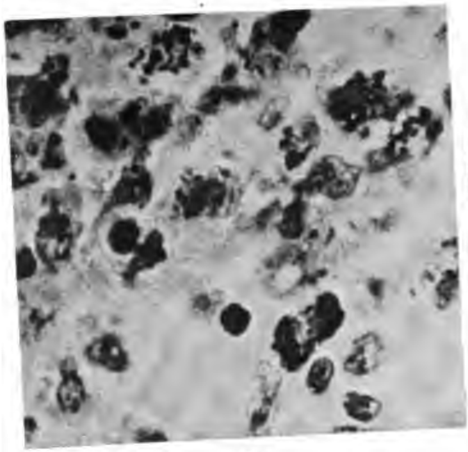

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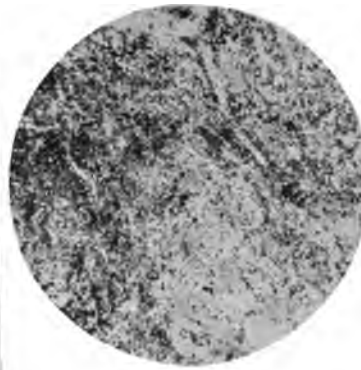

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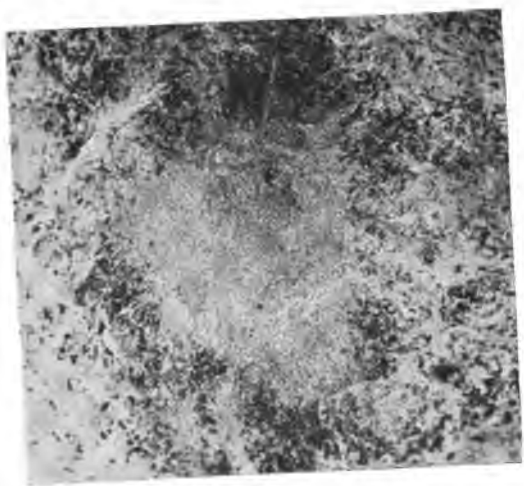

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A Study of the Influence of Varying Densities of City Smoke on the Mortality from Pneumonia and Tuberculosis*

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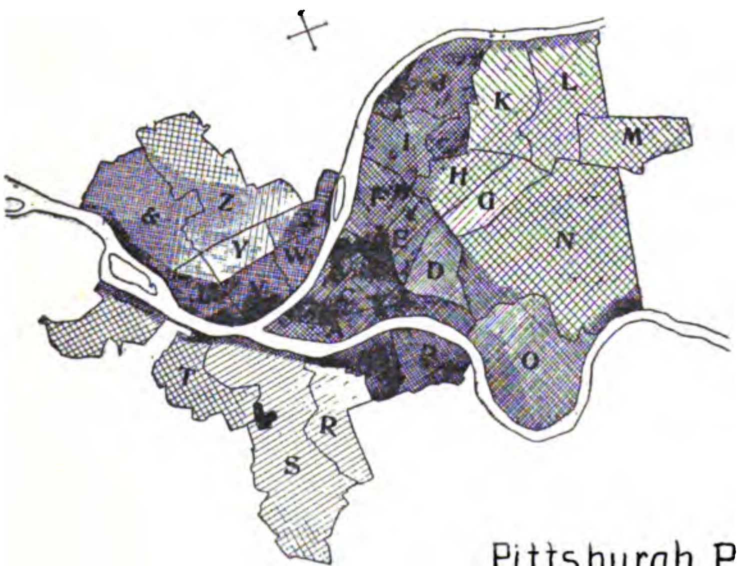
University of Pittsburgh.
AND
C. H. MARCY.

As part of the investigation into the smoke problem, which is being carried on at the University of Pittsburgh, through the generosity of Mr. R. B. Mellon, we have made



Pittsburgh, Pa.
Showing Smoke Areas
by Wards

Chart I

*Reprinted from the Transactions of the Fifteenth International Congress on Hygiene and Demography, held at Washington, D. C., September 23-28, 1912.

COMPARISON OF TUBERCULOSIS DEATH RATE BY WARDS AND SMOKE CONTENT OF AIR BY WARDS

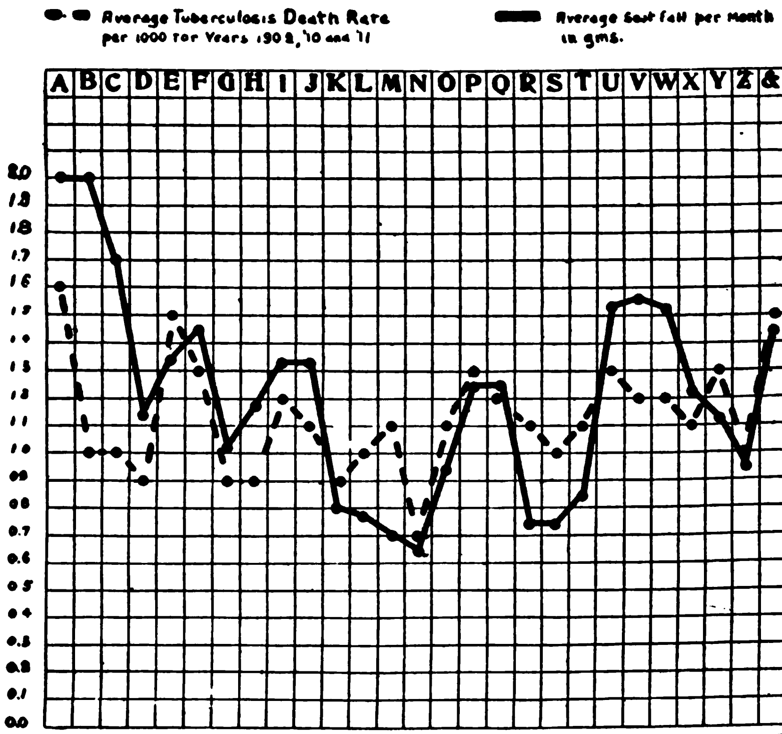


Chart II.

a study of the influence which varying densities of smoke have on the mortality from tuberculosis and pneumonia as typifying acute and chronic pulmonary infections. Perhaps in none of the smoky cities of the world is it possible to go into the influence of smoke in the same way as in Pittsburgh. The peculiarity of the relation of high hills and valleys, in close proximity, within the city limits, makes a well-defined variation in the smoke content of the air. It will be noticed on the map (chart 1) that, along the river frontage, where for the most part the land is low-lying, the air content of smoke is very dense; skirting this dense smoke area, the hills rise more or less abruptly to

varying heights. On the lower hills, as exemplified by C, D, E, J, Y, Z, and &, there is an area of moderate smoke density. Where the hills, however, rise directly from the river to the height of 400 or 500 feet, as exemplified by R, S, T, G, K, L, N, and M, there is comparatively little smoke at any time of the year. During prosperous times, the valley, or dense-smoke area near the rivers, is always heavily laden with smoke. This is true even when there is a brisk breeze blowing.

It is possible, from the division of the city into wards, to rule out a number of other factors, such as poverty, race congestion, and so forth, as an influencing factor in the point of relation which we have brought out by these studies.

It is unfortunate that our figures only cover a period of two years, but this is due to the fact that no records taking account of the wards of the city have been kept prior to this time and also that the number of wards was changed from 56 to 27 three years ago. This renders useless any previous comparison on the ward basis.

The figures which we have obtained are, from one aspect, very convincing, although from another aspect very confusing. It will be noticed for instance, in Chart 4, that in Chicago, where there is a comparatively low smoke content, there is still a very high pneumonia death rate; while in Pittsburgh, with the highest smoke density, there is no higher pneumonia mortality.

The question of smoke density for the various cities has been based upon the reports of the United States Government Weather Bureau. In the various cities which are included in this report the method of determining this density is based on the distance of vision, considering certain fixed objects in the city from an observation center. In Charts 2 and 3, of Pittsburgh, the basis has been certain carefully devised studies of precipitation of air content of carbon dust. These scientific observations have been made in connection with the present smoke study by Messrs. R. C. Benner and C. H. Marcy. In Chart 4, for the sake

of comparison, we have adhered to the Government Weather Bureau report.

The mortality tables, on which Charts 2 and 3 are based, were derived from the health table of statistics of the city of Pittsburgh, and include the years 1910 and 1911.

COMPARISON OF PNEUMONIA DEATH RATE BY WARDS AND SMOKE CONTENT OF AIR BY WARDS.

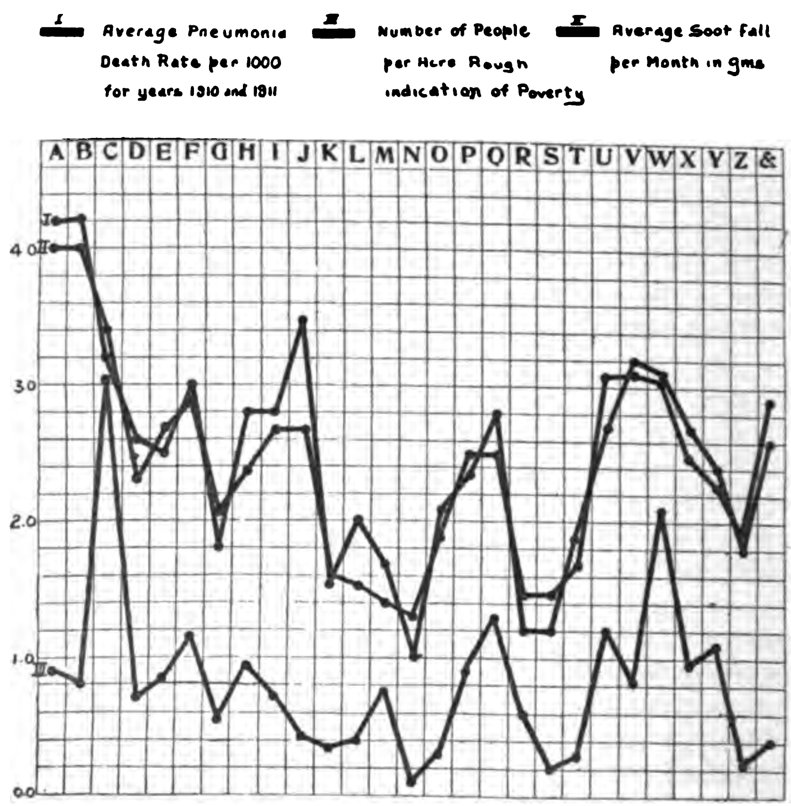


Chart III.

The mortality tables for pneumonia, on which Chart 4 is based, were secured from the Bureau of Census statistics.

We desire to acknowledge here the courtesy and kindness of Director Durand, of the Government Department of Commerce and Labor, for the prompt return of the smoke studies and statistical tables from the various cities, which we scarcely could have obtained without his aid.

Since 1905, Ascher, of Konigsberg, has published tables and studies on the relation of smoke to pneumonia and tuberculosis. Ascher's main conclusions are as follows:

1. The deaths from acute lung diseases are most frequent in children and old people. There is, from year to year, a steady increase in the number of these deaths. This is explained, in part, by the increased contamination of the air by smoke, because the increase in the number of deaths is greatest in districts of an industrial character and not in farming districts. Since 1875 the deaths of infants from pneumonia have increased 600 per cent.
2. There is a noticeable difference in the deaths of acute lung diseases, in those industrial districts where smoke contamination is greater than in those industrial districts where the smoke contamination is less. The number of deaths in coal workers from acute lung diseases is 130 per cent higher than the number of deaths in other workmen from the same cause and of the same age. Hand in hand with the increase of acute lung diseases there is a decrease in the age at death from tuberculosis. This means that the fatal course of tuberculosis in smoky districts is shorter.
3. Animal experiments show that the inhaling of smoke increases the susceptibility of animals to infection by aspergillus. Pneumonia develops in animals which have inhaled smoke more easily than in the control animals.

Ascher's experimental work can scarcely be used as a comparison with the influence of the smoky atmosphere of cities, because he used the smoke or soot of burning petroleum, which forms an insignificant amount of the smoke content of cities and differs very materially from the main content of the smoke of city air.

So far as Ascher's statistical tables are concerned, there can be very little doubt that acute lung diseases are taking a different course to tuberculosis, and one of the most appalling things of modern civilization has been the sharp increase of the mortality rate from acute diseases of the respiratory tract coincident with industrial activity and the consequent irritation by smoke of the

respiratory tract, this being in sharp contrast to the diminution of the chronic diseases of the respiratory tract, as exemplified by tuberculosis.

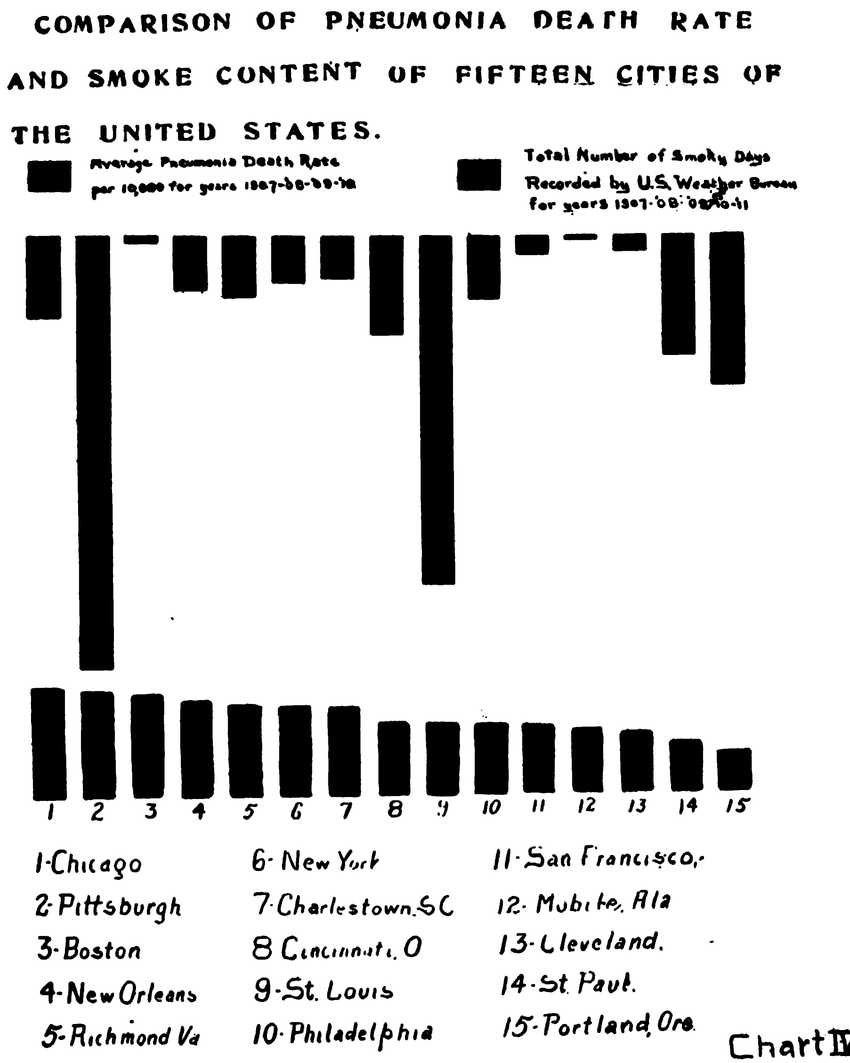
The pneumonia death toll for 1900 for the United States was 105,971; for 1909, 122,400; and for 1910, 136,000; an increase of 10 per cent in one year.

The average death rate from tuberculosis per 100,000 for the 10-year period 1900-1909 was 183; in 1909 it was 160.8; and in 1910, 160.3. This shows a steady decrease.

These figures are examples of the merit which this subject has for our most earnest study.

The chief fact which has stimulated our interest in the pneumonia problem in the city of Pittsburgh has been the terribly acute and fatal type of pneumonia which fills the wards of our hospitals. It can hardly be that this severity of infection has to do alone with the virulence of the germ; nor does it seem likely that it has to do with the generally low type of resistance which Pittsburghers have to this type of infection; rather, it seems more likely that there must be some factor present in Pittsburgh which does not operate in other cities. As we approached this subject we felt sure that we would be able to prove that this factor was the smoke of the iron and steel mills. How signally we have failed in this will be very evident from chart 4, in which is seen the striking contrast between Boston, with almost no smoke, and Pittsburgh, swamped with smoke, yet with approximately the same pneumonia death rate. The same sort of thing is apparent between Mobile, Ala., with almost no smoke, and St. Louis, Mo., with a very high smoke content in its air.

When we attempt to analyze the city of Pittsburgh on the basis of air content of smoke and pneumonia death rate, so striking is the correspondence between the pneumonia death rate and the smoke content of the air of the ward that we are convinced that smoke is a very important factor in the severity of the disease and that some other factor must operate in those cities where the smoke content of the air is not the determining factor in the


COMPARISON OF PNEUMONIA DEATH RATE
AND SMOKE CONTENT OF FIFTEEN CITIES OF
THE UNITED STATES.
Average Pneumonia Death Rate
per 10,000 for years 1907-08-09-10
Total Number of Smoky Days
Recorded by U.S. Weather Bureau
for years 1907-08-09-10-11
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1-Chicago
2-Pittsburgh
3-Boston
4-New Orleans
5-Richmond Va
6-New York
7-Charlestown SC
8 Cincinnati, O
9-St. Louis
10-Philadelphia
11-San Francisco
12-Mobile, Ala
13-Cleveland.
14-St. Paul.
15-Portland, Ore.
Chart IV

pneumonia death rate. This correspondence is more striking even when we put in a line showing that there is no definite bearing of such other factors as poverty, race, and congestion. When, however, one turns to tuberculosis and analyzes the death rate from this disease by wards and charts it in comparison with the smoke content of the air, one finds that there is no association whatever. This corresponds with our clinical observations on between four and five thousand cases of tuberculosis in the last six years. As the result of this clinical study we have come to the conclusion that the general death rate from tuberculosis in Pittsburgh is low—that there is nothing in the smoke content of the air which in any way stimulates the onset of the tubercular process or militates against the rapidity of recovery from tuberculosis when once this disease has been contracted.

In other words, after having made an analytical study of the relation of smoke in the City of Pittsburgh, where it is possible, by virtue of its contour, to separate the atmosphere into "densely laden," "moderately laden," and "comparatively no smoke" areas, and in such a way as to rule out such influences as poverty race, and congestion, we are forced to the conclusion that the smoke content of the air has an apparently important bearing on the pneumonia death rate and comparatively little bearing on the tuberculosis death rate.

From the careful analytical studies of the character of the smoke in the city of Pittsburgh, carried out by Dr. Klotz and Dr. Holman in connection with this same work, there is added a purely chemical and physical reason for this same conclusion, for they have found that the percentage of phenol around the carbon, which pollutes the air, is sufficient to destroy most or many of the organisms with which they have studied when suspensions of these are mixed with suspensions of air smoke.

With this fact in mind it is probably legitimate for one to turn to the pathological studies of these two infections. Pneumonia is a catarrhal condition, and a pre-

disposition for it may be prepared by the irritation of the mucous membrances with foreign substances; but the second (tuberculosis), being granulomatous in type, in which the microorganisms are sequestered and surrounded by cells, the cure of which is accomplished by fibrosis, may naturally be supposed to be aided in the direction of cure by any deposit which stimulates granulation and fibrosis. Some strength is given to this theoretical view by the evidence which we have from anatomical studies, in which we find depositions of carbon particles around the healed tuberculous focus.

One can not help wondering why, when the facts concerning these two diseases are known, so little has been done on the question of pneumonia prevention, when so much has been accomplished on the tuberculosis side of pulmonary infection; and in addition to my remarks upon the relation of smoke to this disease, I should like to again call attention to certain suggestions which I offered a year ago in an address before the Ontario Medical Association for the control of a certain portion of the evils arising from pneumonia. These are as follows:

First. The proper segregation of pneumonia patients and their utensils in hospitals; cleaning, by sprays and washes, the noses and throats of all who nurse and come in contact with these patients; careful hand washing of nurses and attendants after handling; careful destruction of sputum and other discharges; sterilization of linen of patients; fumigation of rooms after occupancy; and the use of gauze, which can be burned, instead of handkerchiefs. These will be the center of the educational crusade.

Second. To have attached to our dispensaries certain nurses who have received special instruction on nursing and preventing the spread of pneumonia, these to be sent to all pneumonia cases in home-nursing work.

Third. The reporting of all such cases to the health department governing the district where the disease exists and the fumigation of the quarters in which the disease has occurred by the department after the death or recovery of the patient.

Fourth. The instruction of the public by pamphlets and school lectures on the necessity for keeping the noses and throats cleansed, especially during winter months; the necessity for controlling the dust of streets by better sprinkling and night sweeping; the evils of bad ventilation in house, public building, and school; of alcohol; of badly cooked poor food; of lack of rest; of worry; of the handkerchiefs; of the bearing on pneumonia of spitting, as well as on other diseases; of the increased resistance generated by open-air sleeping; and similar knowledge. This I am sure, can best be engrafted on the child's mind rather than on that of the adult.

The Influence of Smoke on Acute and Chronic Lung Infections*

WILLIAM CHARLES WHITE

AND

PAUL SHUEY.

Pittsburgh, Pa.

A year ago we started an investigation on the influence of smoke on the various problems of public health. We chose for our study the respiratory tract, as that in which smoke would have its greatest influence by direct contact.

The investigation was carried on under a grant given by Mr. R. B. Mellon to the University of Pittsburgh for the consideration of this problem from all its aspects.

At the International Congress of Hygiene and Demography we made a preliminary report of what had been accomplished up to that time, and while the work reported in the former paper was very incomplete, there seemed to be a rough direct ratio between the number of smoky days in any given city and the number of deaths occurring from pneumonia. On the other hand, there seemed to be an inverse ratio between the number of smoky days and the number of deaths from tuberculosis.

In choosing these two diseases, we were guided by the fact that the one (pneumonia) is an acute inflammatory process of short duration, likely to be influenced by acute irritation, such as would come from foreign particles, and that it represents the most striking malady from the standpoint of increased mortality in the greater number of our cities.

Reprinted from the "Transactions of the American Climatological Association," 1913.

The other (tuberculosis) is a chronic infection, characterized by infiltration and healing by fibrosis, extending over a long period of months or years, and more likely to be stimulated to healing by irritation of inert foreign particles, and yet presenting a constantly decreasing mortality.

Following the presentation of the paper before the Congress of Hygiene and Demography, Dr. John S. Fulton, Secretary of the Congress, called our attention by letter to certain factors, which he felt were of more importance than the simple ratio of smoke to pneumonia mortality, and we have included these in the substance of our present study. The main points in Dr. Fulton's arguments against the conclusions which we tentatively drew from our study were as follow:—

"I would expect Boston to have a greater mortality from pneumonia than Pittsburgh, on the sole basis of fact that Boston has relatively more people in the pneumonia ages. I would expect Chicago to have a higher pneumonia mortality than Pittsburgh, because there is a pneumonia obsession in the minds of the medical profession of Chicago.

"Chicago has relatively more people in the pneumonia ages than Pittsburgh has, and relatively fewer in the pneumonia ages than Boston. I do not think that the pneumonia figures admit of sound reasoning as to magnitude, unless, in the first place, distinctions are made as to the age-distribution of the populations which are to be compared; and, in the second place, unless the pneumonia mortality is divided sharply into two groups, those under and those above the age of three years, and the comparisons made with reference to these distinctions.

"A comparison of pneumonia and tuberculosis magnitudes, as among the cities which you mention, does not prove that the prevalence of tuberculosis in Pittsburgh is low, or that the prevalence of pneumonia is high.

"By mere inspection of those pneumonia charts, without any key to the names of the cities concerned, I would

say that 1, 2, 3, 4, 5, 6 and 7 (Chicago, Pittsburgh, Boston, New Orleans, Richmond, New York and Charleston) are cities fifty years old or older. The last eight (Cincinnati, St. Louis, Philadelphia, San Francisco, Mobile, Cleveland, St. Paul and Portland) are cities less than fifty years of age, and probably situated west of the Alleghenies. I would be right with respect to the first group, and, with respect to the last group, my two errors would be Philadelphia and Mobile."

In choosing the cities for study, we have taken the larger cities scattered widely over the United States, and have tried to get as widely varying conditions from the standpoint of age of settlement, density of population, years of incorporation, flatness of contour as it was possible to obtain.

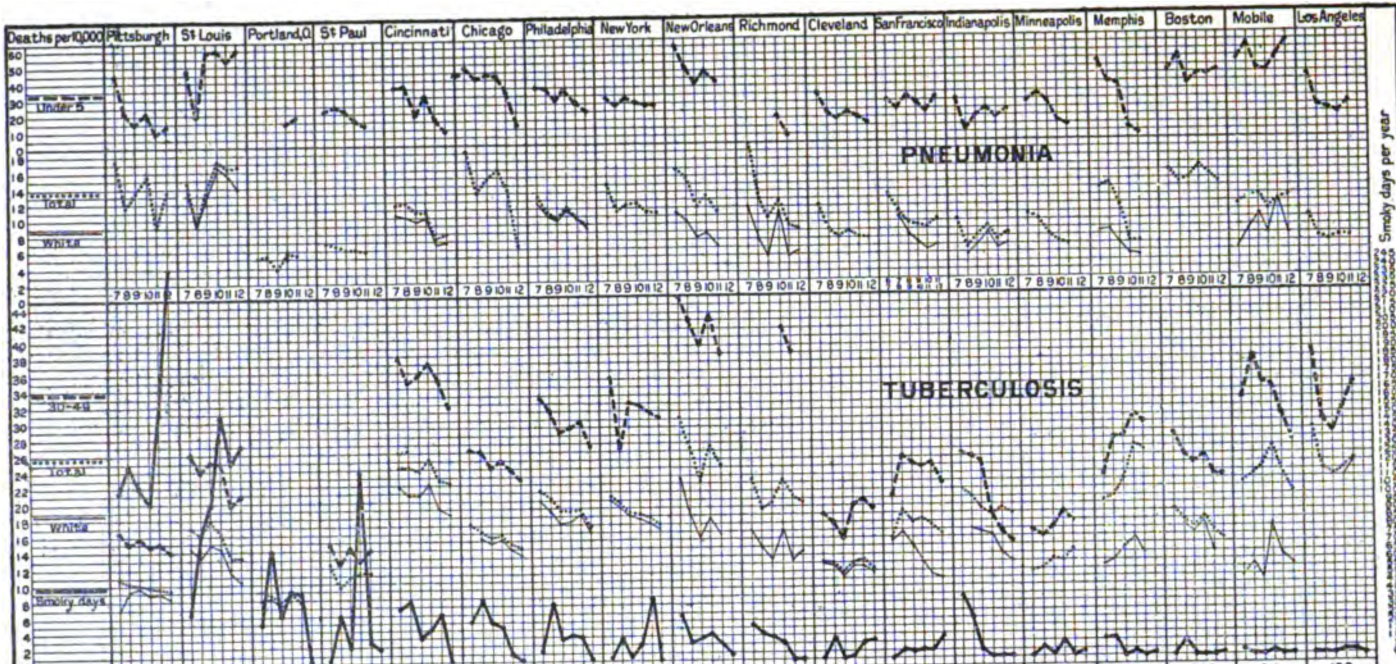
We have also analyzed more carefully the data on which we have completed our present study, and have ruled out as much as possible, in drawing our conclusions, the years and material which were unsafe to use by virtue of their lack of thoroughness.

In the charts accompanying the present study, in the smoke curve we have plotted the number of smoky days per year. In arranging the cities on the charts we have put the smokiest cities first, and so graded on down to the cities in which the smoke was the least. We have considered in arranging them in this way only the 1908 to 1912 periods, preferring to neglect 1907 on account of the unreliability of the mortality data of that year. It will thus be seen that Pittsburgh, St. Louis, Portland, St. Paul, Cincinnati, Chicago, Philadelphia, New Orleans and New York may be grouped as the smoky cities. In this group, however, Pittsburgh, St. Louis, Portland and St. Paul may be classed as very smoky cities.

Beneath these charts the figures represent:—

First (the top line), the number of years since the settlement of the city;

The second line, the number of years since the city was incorporated;



	Pittsburgh	St Louis	Portland, O.	St Paul	Cincinnati	Chicago	Philadelphia	New York	New Orleans	Richmond	Cleveland	San Francisco	Indianapolis	Minneapolis	Memphis	Boston	Mobile	Los Angeles
Age of settlement	159	75	68	144	133	228	232	300	195	304	117	149	92	64	93	283	211	132
Incorporated age	97	59	62	63	94	76	212	260	108	131	77	91	82	53	64	91	99	62
People per acre	20·2	6·4	6·7	14·0	11·4	20·3	18·6	26·0	2·7	20·0	19·2	17·5	11·1	9·4	11·2	25·4	14·6	6·0
[illegible]	147·4	118·2	37·6	35·8	20·8	17·8	16·4	13·0	10·0	8·2	7·2	6·2	5·4	4·2	3·0	2·0	0·4	0·4

The third line, the density of population on the basis of the number of people per acre; and the

Fourth line, the average number of smoky days per year for the five-year period, 1908-1912.

In studying the death ratio of the different cities, we plotted the total death-rate and the death-rate of the white population, as well as the following groups:

Total	population	under	5	years.		
"	"	from	5	to	9	years.
"	"	"	10	"	19	"
"	"	"	20	"	29	"
"	"	"	30	"	49	"
"	"	"	50	"	69	"
"	"	"	70	years	upwards.	

While we plotted all these in the original chart from which this study was made, we have only included a few of them outside the total death-rate in the accompanying charts. In these curves, it is important to bear in mind the history of the registration area of the United States and the great variation in the thoroughness with which vital statistics are kept in the various cities. It was only in 1907 that the registration area approximated 50 per cent. of the population; and only in 1910 was any special attempt made at a uniform method of classification and registration, and this uniform method is not yet in operation in all of the municipalities which we have used. For instance, this classification is not in use in Philadelphia, nor in St. Lous.

In the various curves it will be observed that the year 1907 does not conform to the ratio which has been found to hold in years following this. This may safely be explained by the fact that 1908 was really the beginning of better attempts to place vital statistics upon a more uniform basis; and only in 1910-1911-1912 did we arrive at any real fair basis for comparison.

It must be borne in mind that in comparing with other cities, cities having a large coloured component of population, the mortality by age must be compared on a basis of the ratio of the mortality of the white population to the entire population, because the negro death-rates are much higher than the white.

It will be obvious immediately to anyone who attempts to study this field that the number of smoky days, as furnished by the United States Weather Bureau, is apt to be a very variable quantity, both from the personnel of the recorder and the method by which these readings are made.

The present method of determining the number of smoky days is by fixing the clearness with which certain established objects can be observed from the fixed point of the Observation Bureau. Such factors as the height of the Bureau from the ground, the acuteness of vision of the observer, probably the habits of the observer, the interest which the observer has in the problem, and similar circumstances make it almost impossible to lay down any fixed curve which will be comprehensive for all cities and it would seem a reasonable conclusion that if there is even a rough relation between the conditions which we are studying, it would be safer to say that with more careful figures a more intimate relation could be determined. For instance it is inconceivable that there should be no smoky days for 1910-1911-1912 in a city like Boston, which is largely a manufacturing centre. In the report of the District forecaster for Boston, there have only been two smoky periods in five years. These two periods were five days following September 1, 1908, and five days following October 15 in the same year, and were due to forest fires. While it seems almost incredible that in a manufacturing city, subject to fogs, there should not be more smoky days than is indicated by the forecaster's report, yet it will be noticed that in the Boston curve during this smoky period the pneumonia death- rate- decreased. It is a feature probably not of very serious import that during

that year the pneumonia death-rate fell in all pneumonia groups save that of 5 years of age. This evidence of the reverse influence of the number of smoky days per year on the mortality curve from pneumonia is apparent in several other cities, as for example, Cincinnati.

Between St. Paul and Minneapolis, lying very near together, there is also a marked discrepancy—St. Paul having in 1910 nearly 120 smoky days, and yet the reply from the Forecaster was as follows: "You are informed that said days with record of smoke had reference only to and not to local smoke due to factory chimneys, &c." It seems impossible that St. Paul should be affected with forest fires and Minneapolic not, with a few miles difference in position. This peculiarity of the smoke curve for St. Paul would, of course, put it out of place in this chart, and would explain the difficulty in tracing the same relation which is present in the other cities.

The same thing applies to Portland, from which we have not been able to receive an explanation of the large number of smoky days reported from that city. Portland is probably out of its place in this scheme, as its statistics are not complete.

In summing up these charts, which have been done as impartially as possible, the only constant factor which seems to have any relation is the smoke; in other words, where age of settlement, number of people per acre, and age of incorporation have any apparent influence, this influence must be coupled with the number of smoky days before any satisfactory conclusion can be drawn. It will be seen, then, that if we except Portland and St. Paul, there is a general tendency of the tuberculosis death-rate to rise as the number of smoky days in the city decreases. On the other hand, it will be seen that there is a general tendency for the number of deaths from pneumonia to fall as the number of smoky days in the city decreases. In this instance also, Portland, St. Paul and Boston must be excepted. There seems to be no definite relation, however, between the number of smoky days and the death-rate

under 5 years of age in the pneumonia group. This might readily be expected if we consider as the explanation of the influence of smoke on pneumonia the irritative changes which go on in the mucous membrane of the upper air passages as the underlying factor in this relation, and that these changes would probably take years in their production, or, as Dr. Haythorn has shown, the pneumonia difficulty may be largely one of absorption of exudate, which anthracosis by plugging the lymph spaces largely impedes.

In general, the tuberculosis age-groups are rather uniform in their relation to each other when one comes to the study of individual influences; probably nothing is more striking than the difference between the curve for the total death-rate of the white population as opposed to the coloured. This is most strikingly seen in such southern cities as Memphis, Mobile, New Orleans, and Richmond. There is a striking difference, also, in San Francisco and Los Angeles in the total death-rate from tuberculosis, due, likely, to importation from the middle-west and northern parts of the country.

When one studies individual cities, one finds, as in Pittsburgh, St. Louis, Cincinnati, Chicago, New Orleans, Richmond, &c., a noticeable similarity between the total pneumonia death-rate and the total number of smoky days. This is almost entirely absent in comparing the tuberculosis yearly death-rate, which has persistently dropped in most of the individual cities, save the southern ones, in which there have been curious rises. It is not our intention to enter into explanation of this feature in this paper.

We are at a loss to explain the high mortality rate from tuberculosis in Cincinnati, which seems to be out of its place in the general contour of this chart.

In Boston, in addition to the fact that we believe it out of place from the number of smoky days from a manufacturing standpoint, Dr. Fulton had suggested in his criticism of our former paper that the high pneumonia death-rate in Boston was probably due to the large num-

ber of people in the pneumonia ages (extremes of life). This our age grouping has not demonstrated, as the pneumonia death-rate in all ages is high in Boston. We believe that the factor which is absent in the compilation of this city is the number of smoky days in the year.

Chicago, on the other hand, where Dr. Fulton believes there is a pneumonia obsession in the minds of the physicians, follows very closely what one would expect from the readings of the smoky days. As nearly as we can find, Chicago has been very careful, and since 1910 has forwarded its certificates to Washington, where they have been classified by the Vital Statistics Division of the Census Bureau in order to obviate the reflection of local bias.

We believe that if it were possible to establish a reading of smoky days on the basis which Dr. Benner has established in Pittsburgh, *i. e.,* the precipitation of soot, and have this uniform in the various cities, that we would be able to establish a much more intimate relation between the number of smoky days and the number of pneumonia deaths in any city.

One of the conspicuous things to us in Pittsburgh has been the virulency of the pneumonia infection, which, of course, varies from year to year, but seems to carry its toll off more quickly in Pittsburgh than in any other of the four cities in which I have lived and worked in this field.

It may be well here to again call your attention to the fact that pneumonia is in the main an increasing death-rate in many cities and in the country as a whole; that it takes its victims from the extremes of life; and also takes off many of our most useful middle-aged business men, *i. e.,* many on whom most has been spent in education, at a time when they are most useful to the community; and if it were possible by municipal ordinance to control in some way the production of useless smoke in the cities, much might be done to conserve that on which the community has expended the most, and from which it

may reasonably expect returns in place of death by a rapid illness, such as the one with which we are dealing.

Source of Data.

The mortality statistics are based on reports received through the courtesy of Dr. C. L. Wilbur, Chief of the Division of Vital Statistics of the United States Census Bureau and also through the courtesy of the various Boards of Health of the different cities.

The population statistics and age-distribution for 1910 were obtained through the courtesy of Director E. Dana Durand, of the United States Census Bureau.

The smoke data we obtained through the courtesy of the Chief of the United States Weather Bureau.

Since the Census Bureau report for the year 1900 was as of the population on June 1 while the Census Bureau report for 1910 was as of population on April 15, we utilized the method used by the Census Bureau in estimating the population figures for intercensual years, and after determining the rate of increase, we reduced the estimates of populations to a uniform mid-year basis, *i. e.*, we have them to relate to July 1, with the exception of San Francisco, in which our mortality figures were for the fiscal year. For this city we took the population as of January 1.*

It was necessary to plot population curves to provide a comparison between the population statistics which are furnished on the basis of ten-year periods, starting with five as its unit digit after 35. The mortality statistics, on the other hand, are furnished on the basis of ten-year periods with zero as the unit digit above 30 years of age.

After the population statistics were plotted on this basis, computation was made from these curves for the age periods corresponding to the mortality statistics. The mortality rate per 10,000 was then computed and used in the building up of the curves of the other charts.

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* Bulletin 108, p. 9, and Bulletin 109, p. 9, United States Bureau of Census, Department of Commerce.

Publications of the Smoke Investigation

Bulletin No. 1. Outline of the Smoke Investigation. 16 p. Free.

Bulletin No. 2. Bibliography of Smoke and Smoke Prevention. 164 p. Fifty cents.

Bulletin No. 3. Psychological Aspects of the Problem of Atmospheric Smoke Pollution. 46 p. Twenty-five cents.

Bulletin No. 4. The Economic Cost of the Smoke Nuisance to Pittsburgh. 46 p. Twenty-five cents.

Bulletin No. 5. The Meteorological Aspects of the Smoke Problem. 51 p. Twenty-five cents.

Bulletin No. 6. Papers on the Effect of Smoke on Building Materials. 58 p. Twenty-five cents.

Bulletin No. 7. The Effect of the Soot in Smoke on Vegetation. 26 p. Twenty-five cents.

Bulletin No. 8. Some Engineering Phases of Pittsburgh's Smoke Problem. 193 p. Fifty cents.

Bulletin No. 9. Papers on the Influence of Smoke on Health. 173 p. Fifty cents.

MELLON INSTITUTE OF INDUSTRIAL RESEARCH
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Smoke Investigation Bulletin No. 10

RECENT PROGRESS IN SMOKE ABATEMENT AND FUEL TECHNOLOGY IN ENGLAND

BY
ROBERT JAMES MCKAY
Industrial Fellow, Mellon Institute of Industrial Research

PITTSBURGH, PENNSYLVANIA
1922

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The System of Practical Coöperation Between Science and Industry
Founded by ROBERT KENNEDY DUNCAN

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Introduction

The Multiple Industrial Fellowship known as the "Smoke Investigation," which had for its object the abatement of the smoke nuisance, was founded in 1911 and continued in operation until 1914. It was intended by its donor, a prominent Pittsburgh business man, rather as a benevolence than for purposes of personal profit, and it constituted a fellowship many times larger than any which had been established up to that time for any purpose whatever or in any institution. During the two years of its operation, the Smoke Investigation completed nine distinct inquiries which were published in bulletin form (see list on inside of the back cover of the present Bulletin), and its findings led to improvement of conditions in Pittsburgh and initiated and aided in the direction of inquiries of a similar nature elsewhere.

The present Bulletin summarizes a report made by Robert James McKay, an Industrial Fellow of the Institute, who was sent abroad during the early part of 1922 by the same donor, whose deep interest in smoke abatement continues and who thought that the results of researches recently carried out in England should be available to Americans interested in civic welfare and municipal hygiene.

EDWARD R. WEIDLEIN,
Director.

Pittsburgh, Pa.,
August 1, 1922.

Contents

PART I.

SMOKE ABATEMENT IN ENGLAND

SCOPE OF THE INVESTIGATION

Visits were made to the principal localities in Great Britain where valuable information could be obtained on smoke abatement and fuel technology. Men recognized as authorities, both on legal control and on the manufacturing and practical sides, were interviewed. The general conditions of smoke production and smokiness of the atmosphere were observed, and the most efficient combustion apparatus was inspected.

The cities visited were London, Glasgow, Manchester, Newcastle, Leeds, Sheffield, Barnsley and Liverpool. The opinions of about one hundred specialists were obtained, thirty-five by personal interview and the remainder by published or written statements or statements made through other parties. A list of these specialists is given at the end of the Bulletin on page 58.

The principal societies and organizations interested in smoke abatement were consulted; namely, the Coal Smoke Abatement Society, of London; the Smoke Abatement League of Great Britain; the Committee on Smoke and Noxious Vapors Abatement of the Ministry of Health; the Advisory Committee on Atmospheric Pollution of the Meteorological Office; the Air Pollution Advisory Board of the Manchester City Council; the Fuel Economy Board of the Federation of British Industries; and the Fuel Research Board of H. M. Department of Scientific and Industrial Research.

Representative plants were visited which contained the best and newest apparatus for smoke abatement and efficient combustion. These included the Dalmarnock Electrical Supply Co., Glasgow; the Carville plant of the

Newcastle Electric Supply Co., Newcastle; the West Ham Corporation Generating Station, London; the Dalmarnock Gas Co. and the Edgar Allen Steel Works, Sheffield; Low-Temperature Carbonisation, Ltd., Barugh; MacLaurin Smokeless Fuel Co., Grangemouth; and others.

Particulars regarding smoke abatement in Germany were obtained from reports made by specialists who recently had visited Germany to study the subject.

The field investigated was too broad to attempt to make any detailed analyses of costs, operating data, etc. Therefore conclusions were drawn entirely from the opinions of the authorities consulted, taking into account their standing and the existence of possible prejudices. In most instances, it was possible to obtain a decisive weight of dependable opinion on one side or the other of debatable points; but in a few cases the conclusions were necessarily doubtful, and, where this is true, it has been indicated.

This report describes the general aspects and important features of the investigation. The mass of data obtained, in the form of publications, written statements and notes, is filed and indexed for reference in connection with the report.

General Summary of English Conditions

The atmosphere of most of the manufacturing cities of England is less pure than that of Pittsburgh, as determined by visual observation. The deposits of soot and dust in buildings and streets are heavier, and the air contains more suspended matter, both in damp and dry weather. The number of industrial stacks emitting visible smoke is greater, and, in addition, smoke issues from chimneys in nearly every dwelling house. That the dirt and haze are due almost entirely to coal smoke was proved by the remarkable cleanliness of the streets and clarity of the atmosphere during the recent coal strike.

Fig. 1.—The Tower of London (Bloody Tower), showing decayed Gatton stone above and new Chilmark stone below. This picture is illustrative of the effect of a smoke-laden atmosphere. The photograph was taken in 1920.

There is much public interest in methods or processes of such a fundamental nature that, if they could be put into operation, the whole smoke problem would be solved. Typical and most important of these processes is that of low-temperature carbonization, which attempts to extract the bulk of the valuable volatile material from coal and at the same time leave a smokeless fuel, the combustion of which would not be improved by expert attention or special apparatus. England is probably ahead of America in the development of such comprehensive schemes. On the other hand, actual use of the best-known smoke-reducing appliances is not as general in England as in America. While knowledge of such appliances is disseminated widely and their value is recognized, their adoption has been slow.

Not much progress has been made in the development of new apparatus during the last few years because the work of perfecting such apparatus has far outstripped its adoption by smoke producers. Therefore, any further improvement in conditions must come by other means than new apparatus for direct combustion.

The legal methods of smoke control are quite similar in the various cities and localities. The minor differences in the laws affect conditions less than the personnel of the officers in charge of their enforcement. The amount of smoke seems roughly proportional to the amount of coal burned, with the exception of the pottery and steel manufacturing districts, which are worse than any others. The laws are less effective than the Pittsburgh ordinance and they are not as well enforced. The co-operation of the people of Glasgow with the smoke inspectors and the work done by the Inspection Department of Sheffield, in co-operation with steel manufacturers, to develop apparatus for special cases, are worthy of mention.

Several societies which have for all or part of their purpose the abatement of smoke, carry on active cam-

paigns which have been instrumental in causing much improvement. The Coal Smoke Abatement Society, of London, is the foremost of these organizations. One of the most valuable developments of the work of this Society has been the formation of the present branch of the National Meteorological Office (weather bureau), which determines and records exact data regarding smoke pollution. The Smoke Abatement Society was also instrumental in instigating the appointment of the Ministry of Health Committee on Smoke and Noxious Vapors, which has made valuable recommendations regarding legal control.

The following extracts from letters from two well-known English authorities are enlightening in expressing two phases of opinion:

"Manchester, 14th Mar., 1922.

"In my opinion, we cannot possibly prevent black smoke in England unless we burn smokeless fuel. You have got to remember that over here we use open-fire grates in houses, and that 35,000,000 tons of semi-bituminous coal are burnt per year for this one purpose alone. It is absolutely impossible, on our present knowledge, to prevent black smoke with semi-bituminous coal in household fires, and, in my opinion, household fires account for about 50 per cent. of the black smoke of Great Britain, which opinion is based on the exhaustive research work now being carried out by Dr. J. G. Owens, of London. You in America of course use closed stoves, which do not make smoke, or, at any rate, nothing like to the same extent.

"As regards factory smoke, if the most careful and scientific means of burning fuel are adopted, about 80 per cent. of this smoke can be prevented; that is, about 40 per cent. of the smoke of the country. The trouble is, however, that manufacturers in this country, as in other countries, will not adopt modern scientific methods, either because they are too lazy or too ignorant, and there are no effective laws to compel them to take the most elementary measures to prevent black smoke. We have got to remember, however, that bituminous coal is a difficult fuel to burn, so as to prevent the escape of volatile matter in the form of smoke and unburnt products. The real remedy, as I said, in my opinion, is to burn smokeless fuel. It is naturally out of the question to burn anthracite because only about 6 per cent. of the coal in this country is in the form of anthracite. It is also not a practical proposition to burn coke or gas from the gas works process. Coke is not a nice fuel, as it is ignited with great difficulty, and it has a smell and causes a very unpleasant and dry atmosphere in the room. Also, gas is not satisfactory, as gas fires, in my opinion, are extremely unhealthy and are apt to be dangerous, and are also too expensive.

"The remedy is undoubtedly low-temperature carbonisation of coal; the residual fuel is absolutely smokeless, no matter how careless or inefficient the firing may be, and is also an extremely efficient fuel, burning with a high emission of radiant heat."

(Signed) DAVID BROWNLIE.

"Coal Smoke Abatement Society, 11th April, 1922.

"A fortnight ago our Society organized a most influential deputation to Sir A. Mond, the Minister of Health. We urged that the Government should introduce a Bill to give effect to the recommendations of Lord Newton's Departmental Committee on Smoke Abatement. There were about 100 representatives of distinguished Societies and large Local Authorities there, and the deputation has attracted a good deal of attention. We were very sympathetically received and the Minister came out as a warm advocate of the Smoke Abatement movement.

"Our Council has just completed the work of preparing a Bill* which is being submitted to the Government, and if they will not introduce it Lord Newton has promised to do so as a private member, so I hope that the movement in England will soon receive a great impetus."

(Signed) LAWRENCE W. CHUBB,
Secretary.

SUMMARY OF SMOKE-ABATEMENT DEVELOPMENTS

This summary presents briefly the principal interesting factors in smoke control in England and mentions the possibilities for their application in the United States, especially in Pittsburgh.

1. LEGAL CONTROL.—The legal control of smoke in England is largely by national laws, and the enforcement of these laws is in the hands of local health authorities. His Majesty's Ministry of Health recently appointed a committee to investigate the operation of these laws and to recommend improvements in them. This committee has made its final report, recommending certain changes which include the placing of responsibility for enforcement in more capable hands and standardization of the kinds of smoke prohibited; this will enable larger fines to be imposed. These changes will effect an improvement in the present English law; but, even with the improvement, the law will not be as satisfactory as that of Pittsburgh.

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*The provisions of this bill are given on page 18 *et seq.*

The national uniformity of the laws is of great value in Great Britain, but it is believed that such nationalization is not practicable in the United States.

2. MEASUREMENT OF ATMOSPHERIC POLLUTION.—H. M. Meteorological Office (weather bureau) includes a department whose business it is to measure and record conditions of atmospheric pollution throughout the United Kingdom. This department has developed efficient recording and indicating apparatus for measurement of suspended impurities and dust fall, and the instruments are reasonably cheap and easy to operate. Measurements with this apparatus are made in all parts of Great Britain, and the results are summarized and published in the London office. The recording of such data on conditions of smoke pollution is of much importance in determining the progress of abatement. It is believed that the installation of a similar system in the United States would be influential in reducing the smoke nuisance.

3. EDUCATION OF FIREMEN.—Most industrial districts have access to technical schools wherein workmen may receive instruction on various aspects of their work. There have been several attempts to conduct, in these schools, courses for the education of firemen and some of these have been fairly successful. It is claimed that such education has been useful in reducing smoke and it is generally believed that more work along this line would be worth while. Several men expressed it as their opinion that the work of firing should be as much a trade as, for instance, bricklaying, and that the requirements for holding a position as fireman should be as great.

Means for the training of firemen should be available in Pittsburgh and requirements should be established for men who hold positions as firemen.

4. Publicity and Public Education.—Several of the smoke abatement organizations, as well as the city governments, are doing considerable work along publicity lines. As a result, the average educated Englishman realizes that the presence of smoke is damaging to his health and is intrinsically expensive. This is a distinct aid to smoke abatement. At the same time, there is still a feeling among a large class that smoke is an indication of industrial prosperity and this feeling is a great drawback to attempts to abate smoke.

It is believed that a constant campaign of public education in this field would be valuable in Pittsburgh. The recording and publication of data on atmospheric pollution, as suggested above, would be a logical beginning for such educational work.

5. Smoke-Consuming Appliances.—The most progressive English fuel consumers know and use the best stoking appliances, smoke filters and combustion-control apparatus; but, on account of the lack of legal pressure and of interest in fuel economy, there is a large output of smoke from industrial plants. These mechanical appliances are better known in the United States than in England and most of them have been described in Bulletin No. 8 of the Mellon Institute's Smoke Investigation Series. Some of the more modern developments which may be mentioned are the use of forced mechanical draft, preheating combustion air and improved recording devices. The use of balanced mechanical draft and of carefully planned combustion arches is common in the best English plants. These devices do not seem to have been improved very greatly within the last few years and smokeless combustion depends more upon the ability of the fireman to operate them successfully than upon the particular type of apparatus used. Complete information regarding these devices may be found in the publications of the

various large concerns which manufacture them. Practically no value has been found in apparatus for filtering or cleaning smoke after it leaves the furnace.

6. Low-Temperature Carbonization of Coal.—Several experimental plants are approaching commercial operation of this process. In addition, there is much laboratory experimentation going on and almost every English fuel engineer has a scheme of his own for such a process. If successful, it would practically eliminate smoke by producing an easily burned smokeless fuel while conserving the value of the volatile constituents of the coal.

This process is particularly applicable to English conditions, since the fuel produced would be especially valuable for the open fire-places which are the universal sources of heat in private houses. Its possible application to conditions in the Pittsburgh district depends on a great many factors on which data are not at present available; but it offers interesting possibilities which should be investigated thoroughly.

7. Electrification.—A recent Act of Parliament has divided the country into districts, each of which is to obtain its electrical supply from one company. The proper operation of this scheme should induce a much more general use of electricity to replace small coal-burning units, which would reduce smoke by putting a greater percentage of the coal burned under supervision of expert firemen, equipped with the best combustion apparatus.

8. Coal-Dust Firing.—There is probably less development along this line in England than in the United States. However, valuable progress is being made in the use of so-called "unit" pulverizers which feed only one burner or one furnace. This system undermines the usual arguments against coal-dust firing—great expense of first

installation, danger of explosions and general unwieldiness—and therefore increases the possibilities of application. While this process produces smokeless combustion, it often permits a large proportion of ash to be driven out of the stack.

9. COAL FLOTATION.—A large amount of experimentation is being done along this line, particularly in educational institutions, and one or two commercial plants are being operated. The production of a cleaner fuel by this means may aid to a certain extent in efficient combustion.

10. INCREASE IN THE USE OF GAS.—The various firms interested in the manufacture of gas and equipment for gas plants are active in publicity in the interest of a greater use of gas. This has resulted in a material increase in this use, especially in domestic appliances, with a corresponding decrease in the amount of smoke. This movement does not seem to present any particular possibilities for application in Pittsburgh.

ACTIVITIES OF VARIOUS ORGANIZATIONS

THE COAL SMOKE ABATEMENT SOCIETY.

This Society was founded in 1899 for the purpose of abating coal smoke, the promotion and encouragement of the use of proper apparatus for abating smoke, and to procure the enforcement of the existing law on the subject and the extension of the law where necessary. It has been the most active and useful organization in Great Britain on the subject, and is composed of influential men actively interested in the field. The Society is supported by gifts of money from the members and other interested parties and is entirely dependent on them. Because of this fact it is often hampered in its work by lack of funds. The gifts are small ones, as there are no organizations

or other sources which can be relied upon to furnish a large part of the necessary support. The Society has offices at 25 Victoria Street, where it is represented by the Secretary, Lawrence W. Chubb. It operates very largely in London, but does not confine itself to this locality and takes interest also in the problem throughout Great Britain. It holds fortnightly meetings.

One of the activities of the Society was the formation of classes for the education of stokers or firemen. These classes were held in the evenings in parts of London which would be easily accessible to the stokers, and were taught by competent practical engineers, whose services were paid for by the Society. A nominal fee was charged for instruction, which was sufficient to insure the stoker being interested in the class before attending. This fee was paid in some cases by the stokers themselves and in some cases by their employers. A certificate was issued to those who did well in the course, stating that the man was a competent stoker and was recommended by the Society. These certificates were of value to the men in obtaining good work and good pay and were well appreciated by them. Classes were held for a sufficient length of time to demonstrate their value, but have since been dropped by the Society because of the lack of funds.

At times the Society has had smoke inspectors in the field who co-operated with the inspectors of the Government and thus helped in the abatement of certain nuisances. In certain districts these inspectors have demonstrated the possibility of decreasing the smoke nuisance by proper control. The methods of inspection and control are a combination of advice to the works which are producing smoke, formal warnings where sufficient improvement does not occur after this advice, and prosecution and fine where necessary. The inspectors have collected interesting data regarding the number of chim-

neys producing smoke in different localities and the improvements, or the opposite, which have occurred.

The Society has made a survey of opinions of various manufacturing concerns regarding special appliances for abating smoke. This survey took the form of a questionnaire sent out to some 400 firms which had formerly been offenders in regard to smoke, but which had shown definite improvement in the last few years. The questions were as follows: (1) What mechanical device or other means do you employ for preventing the issue of smoke from your chimneys? (2) Do you find the system you use efficient? (3) Have your efforts led to any economies in working? (4) Do you consider that the advantages gained to yourself and the community are worth the effort expended? (5) Have you any objection to your name being made public in connection with your answer? In general, the answers to these questions do not bring out the use of any appliances or other means which are not known in Pittsburgh and mentioned in other parts of this report. The greatest factor in improvement has been the education of stokers or firemen and the intelligent use of stoking appliances.

The Society held, in 1912, an exhibition and symposium on smoke abatement and dust prevention. This exhibition was attended by interested parties from other countries as well as England and has been a very valuable factor in crystallizing public opinion in favor of smoke abatement. All kinds of appliances for the purpose of smoke abatement were exhibited and papers were read on various phases of the subject. This exhibition was a great success and it was intended to continue it at intervals of two or three years, but the war intervened and the exhibition has not been repeated. However, it is now planned to hold a second exhibition in 1922. The date was at first set in March; but, on account of the inability

to obtain a suitable hall in which to hold it at this time, it has been postponed and will be held in the fall, probably in November.

The exhibition will be under the joint direction of the Coal Smoke Abatement Society and the Worshipful Company of Fanmakers. The "council" in direct charge of the exhibition is composed of mayors of the manufacturing cities and of representatives of technical institutions and societies interested in smoke abatement. The exhibition will include illustrations of the production, distribution and use of gas, electricity and oil for various purposes, and of the uses of smokeless fuel. Mechanical stokers, special furnaces, boiler fittings, and other accessories will be shown. Papers will be given regarding progress in smoke abatement in various localities. L. W. Chubb and others in close touch with the preparations for the exhibition are very anxious to have a paper telling what has been done in smoke abatement in Pittsburgh, and, if possible, a representative from Pittsburgh to attend the exhibition.

The Meteorological Office Advisory Committee on Atmospheric Pollution.

This committee was appointed as a result of the International Smoke Abatement Exhibition in 1912. It was realized at that exhibition that few exact data existed regarding the smoke nuisance and this committee was formed to gather the information. It was entirely unofficial at first and was supported by the Coal Smoke Abatement Society; but, as its work was found more and more valuable, it received official recognition, and in 1915 it was made a permanent part of the Meteorological Office, to gather and record data on atmospheric pollution.

The committee has developed an apparatus for the determination of the amount of dust-fall during a given period; a recorder which automatically shows the amount of soot content of the atmosphere on a chart which is changed every 24 hours, and an apparatus for counting the number of suspended particles in the air at any moment. These pieces of apparatus are all effective and useful. That for determining soot-fall has been in use all over the United Kingdom for about six years, the automatic recorder has come into general use during the last two years, while the apparatus for counting the number of dust particles in the air has only just been developed.

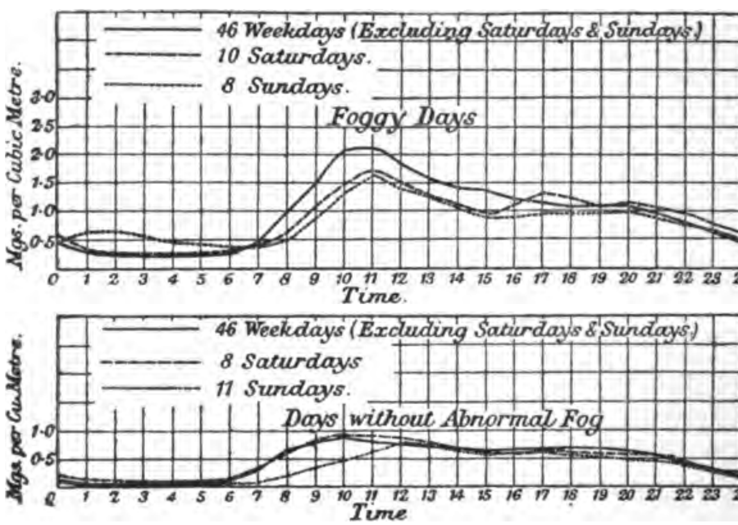


Fig. 2.—The suspended impurity in the air of Westminster, London, England, during the winter of 1920-1921. These data were collected by the Meteorological Office Advisory Committee on Atmospheric Pollution.

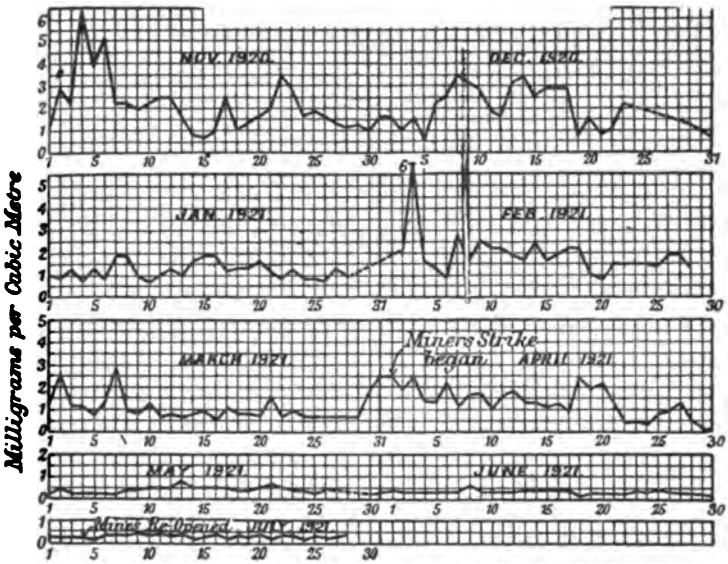


Fig. 3—The maximum suspended impurity each day in milligrams per cubic meter, Westminster, London, England. These data were collected by the Meteorological Office Advisory Committee on Atmospheric Pollution.

The committee establishes stations for these instruments in various places of interest throughout Great Britain, and collects and tabulates the data obtained in a report which is issued in the spring of each year. Quite complete and interesting figures have been obtained regarding the fall of dust throughout the British Isles. The apparatus for determining the soot content of the atmosphere has not been in operation long enough to give extensive results, but the data which have been found are of considerable interest. None but the most preliminary results have been obtained with the apparatus for instantaneous counting of dust particles. These pieces of apparatus are described in another part of this Bulletin (see page 30).

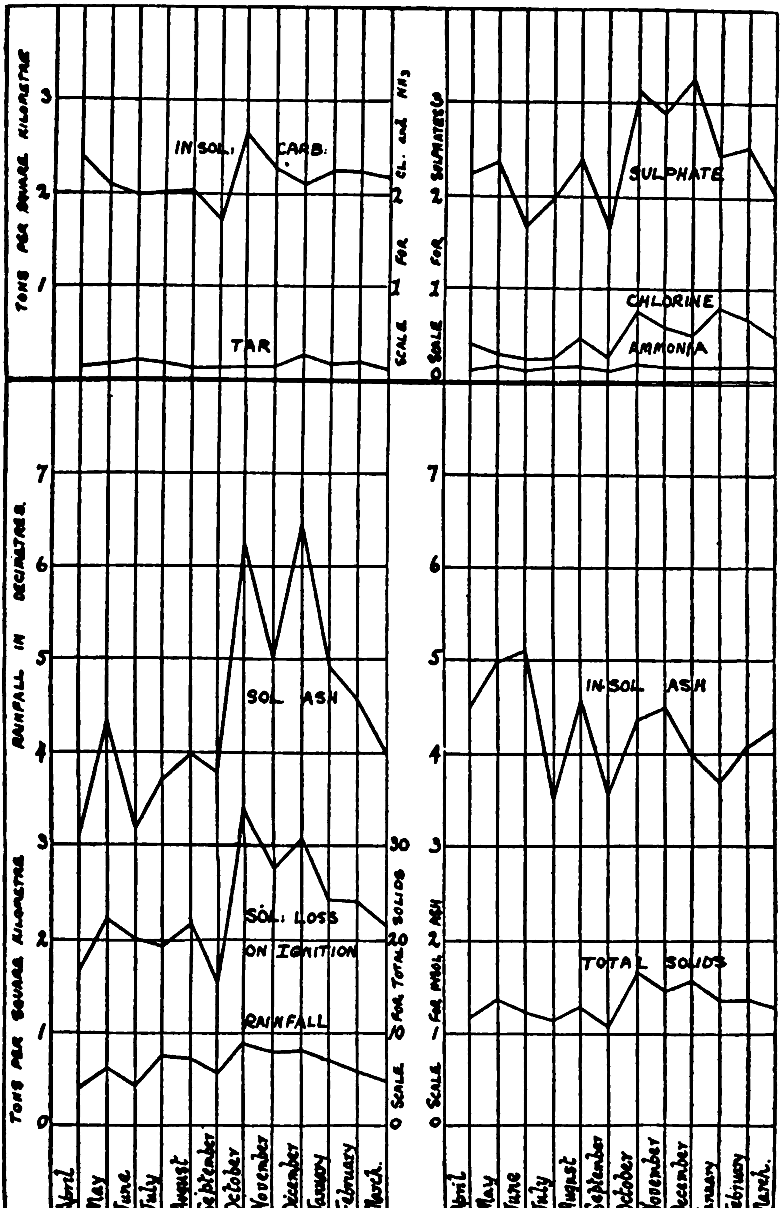


Fig. 4—Curves of average deposit of each type of pollution for each month for a group of nine stations maintained by the Advisory Committee on Atmospheric Pollution, April, 1915—March, 1919.

The work of the committee is carried on by its head, J. S. Owens, with one technical assistant, and a stenographer. The determinations in the field are made by the city chemists and are reported by them to the committee. The taking and recording of data have been quite satisfactory, with the exception of determinations in particularly smoky cities. From certain of these cities it has been found increasingly difficult to obtain data, and at some places the apparatus has been discontinued by the municipalities. This is because of the reluctance of officials to admit that their cities are exceptionally smoky.

The Ministry of Health Advisory Committee on Smoke and Noxious Vapors Abatement.

This committee was appointed by the Right Hon. Christopher Addison, Minister of Health, to consider the state of the English law with respect to smoke abatement and to make recommendations as to desirable changes in the law and its administration. The chairman of the committee was Lord Newton and the Secretary was E. C. H. Salmon. Its membership included the most influential names in the United Kingdom which have been connected with the cause of smoke abatement, and the report of its investigation constitutes a weighty and valuable survey of smoke conditions. Its work was finished during last year and the final report was submitted in December, 1921. The recommendations of the committee are now being considered by the Ministry of Health for official proposal as an Act of Parliament. It is very probable, however, on account of the present business depression and the general feeling that every effort should be made to encourage industry and no chance of producing discouragement taken, that no move will be made at present. If no official move is made, it is probable that Lord New-

ton and other members of the committee will personally introduce the bill and attempt to put it through.

The committee was first appointed in 1914 and started its work then. It was discontinued during the war and recommenced in 1920. Its purpose was "to consider the present state of the law with regard to the pollution of the air by smoke and other noxious vapors, and its administration, and to advise what steps are desirable and practicable with a view to diminishing the evils still arising from such pollution." Evidence was taken in Manchester, Glasgow, Stoke-on-Trent, Sheffield and Swansea, and two members of the committee visited Germany and studied conditions there. Over 150 witnesses were examined.

The committee made a study of the present law and the laws and movements leading up to it. They consulted men interested in smoke abatement throughout the country and men in industries which are recognized as smoke makers, to obtain their ideas as to the possibility or desirability of further legislation and their opinions on new appliances and developments in regard to smoke. The summary of the recommendations made by this committee is as follows:—

(a) With Regard to Industrial Smoke:

(1) That the Minister of Health should be given clearly defined power to compel or act in place of any defaulting authority which refuses to perform its duty in administering the law with regard to smoke. (Paragraph 97.)

(2) That the general legal obligations of all manufacturers, users, and occupiers of any business premises or processes, engines or plant of any description whatever, should be to use the best practical means, having regard to all circumstances of the case, for avoiding the pollution of the air by smoke,

grit or any other noxious emissions; that the same law should also apply to all Government establishments and all rail and road locomotives and motor cars of whatever weight or type, and to steamers on rivers, estuaries and lakes.

It must be clearly understood that questions of cost must be taken into account in determining what is practicable. (Paragraphs 80-81.)

(3) That the Minister of Health should be empowered to fix standards from time to time; and in any case in which the emission exceeds the standard so fixed, the onus of proof that the manufacturer is using the best practicable means should be on the manufacturer. (Paragraphs 82-86.)

(4) That the duty of enforcing the law with regard to pollution of the air by smoke should be transferred from the local sanitary authorities in whose jurisdiction it now rests to the county authorities, i. e., the Councils of Counties and County Boroughs; minor authorities should still have power to take proceedings if they so desire. (Paragraph 93.)

(5) That the Minister of Health should be empowered to constitute Joint Committees consisting of two or more Councils, in cases where it appears to him that this course would lead to the better administration of the law with regard to smoke in any given area. (Paragraph 95.)

(6) That the Minister of Health should assign to one or more competent officers the duty of advising and assisting local manufacturers and authorities with regard to difficult smoke problems; these officers should report annually on the steps which are being taken and the progress which has been made in the suppression of avoidable smoke. (Paragraph 96.)

(7) That the law should enable much larger fines to be imposed than at present. (Paragraph 90.)

(8) That legislation should be introduced at an early date with a view to consolidating in one measure the various existing statutory provisions with regard to the pollution of the air by smoke, and providing for their amendment where necessary to give effect to the above recommendations. (Paragraph 91.)

(b) WITH REGARD TO DOMESTIC SMOKE:

(9) That the Central Housing Authority should decline to sanction any housing scheme submitted by a local authority or public utility society unless specific provision is made in the plans for the adoption of smokeless methods for supplying the required heat as suggested in our Interim Report. The only exception to this rule should be when the Central Authority is fully satisfied that the adoption of such methods is impracticable. (See Section VII, Recommendations, of the Interim Report, Appendix B.)

(10) That the Government should encourage the co-ordination and extension of research into domestic heating generally. This is a matter of great importance in view of the many outstanding problems which demand inquiry. (See Section VII, Recommendations, of the Interim Report, Appendix B.)

(11) That local authorities should be empowered to make by-laws requiring the provision of smokeless heating arrangements in new buildings other than private dwelling houses, such, for example, as hotels, clubs, offices and the like. (Paragraph 62.)

(c) GENERAL:

(12) That Gas and Electricity Undertakers should be given every facility and encouragement to increase and cheapen the supply of gas and electricity, and that the practice at present followed by some municipal authorities of overcharging for gas and electricity in order to allocate the profits thus accruing, to the relief of the rates should be discontinued. (See Section VIII, Recommendations, of the Interim Report, Appendix B.)

(d) WITH REGARD TO NOXIOUS VAPORS:

(13) That the Alkali, &c., Works Regulation Act, 1916, should be amended so as to apply generally to all manufactures from which noxious vapors might come. (Paragraph 106.)

(14) That a list of such noxious vapors should be included in the Act, and the Minister of Health should be empowered to add to this list from time to time other noxious vapors, after due inquiry. (Paragraph 110.)

(15) That a general obligation should be placed on every manufacturer of using the best practicable means for preventing the escape of noxious or offensive vapors. (Paragraph 107.)

(16) That the present system of registration should be continued, and the Minister of Health should be empowered to require the registration of classes of works not at present required to be registered. (Paragraph 109.)

(17) That the Minister of Health should be empowered to fix standards from time to time, after due public inquiry, with regard to noxious vapors in cases where he finds it desirable; and these standards should have the same legal force as those which we recommend with regard to smoke. (Paragraph 108.)

Smoke Abatement League of Great Britain.

This league was formed in 1909 to carry on the work of smoke abatement in the Provinces in somewhat the same way it is carried on by the Coal Smoke Abatement Society in London. The organization co-operated with the Coal Smoke Abatement Society, but was not connected directly with it, although it was supported in the same way. There were four local "branches,"—at Manchester, Glasgow, Sheffield, and Warrington. These branches were affiliated and were part of the National League whose headquarters were at Manchester. Twenty-six municipalities in Great Britain were members. The organization operated until some time after the beginning of the war, when it ceased operations and has not begun again. Some recommendations were made by it as to legislation necessary and means of enforcing it, and a general study was made of smoke conditions throughout the country, inspectors having been employed to make this study. The league has not been any considerable power in smoke abatement, although it might have assumed importance if the war had not intervened.

Sir Oliver Lodge was president of the league, and E. D. Simon and John W. Graham were influential members.

The Air Pollution Advisory Board of the Manchester City Council.

This board was appointed by the Sanitary Committee of the Manchester City Council in 1912. Its purpose is to "investigate the conditions of air pollution prevailing in the City of Manchester, and the best means of avoiding or minimizing the same." The board is not concerned with prosecutions or offenses against the laws but confines itself entirely to research and propaganda. The board has four sub-committees: (1) The chemical sub-

committee is carrying out a thoroughly scientific investigation of the nature and amount of soot and other impurities in the air and the loss of sunlight in Manchester due to the presence of smoke. It is also conducting an investigation into the efficiency of various forms of household heating appliances and the fuels used in them. This research is being conducted in co-operation with the Department of Scientific and Industrial Research of the National Government, which pays part of the expense of the investigation. Indeed, the research work, which is under the supervision of Dr. Margaret Fishenden, is being taken over entirely by the Department of Scientific and Industrial Research. (2) The statistical sub-committee is gathering data on the economic loss caused by smoke, both by waste of fuel and by damage done by smoke. The sub-committee has published some interesting papers on these subjects and has given publicity to the general question. (3) The legal and administrative sub-committee considers the state of the law on the subject and the possibility of improvement in the law or its enforcement. (4) The engineering sub-committee considers the improvements possible in combustion and smoke-consuming appliances.

This board is an active department of the Manchester City Council. The Chairman is W. D. Simon, Lord Mayor of Manchester, and its membership includes many influential men of the city. It co-operates with the smoke abatement societies and committees of other parts of Great Britain in the exchange of data.

The Fuel Economy Department, Federation of British Industries.

The Federation of British Industries is an association which includes about 90 per cent. of the industrial concerns of Great Britain. Its purpose is co-operative

action in all cases where such action would be of value to the majority. It is particularly valuable in influencing legislation for industrial prosperity and preventing legislation which would hamper industry. Its work includes lowering of costs, promotion of research, and anything advantageous to general commercial efficiency.

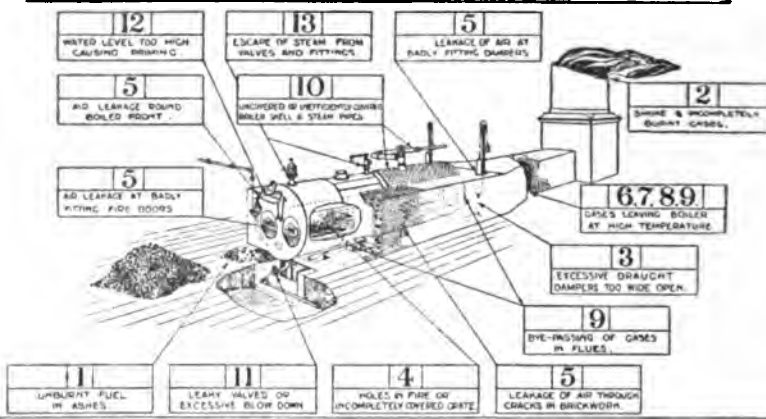
Economy in the use of fuel makes for general industrial prosperity and is therefore a problem which falls within the scope of the work of the federation. A fuel economy committee was appointed during the last years of the World War, when the immense importance of the fuel supply was in the forefront of public attention. This committee has appointed a "technical sub-committee," composed of the best fuel technologists of the country, and these specialists supervise the operation of the fuel economy department. Departments of like character also exist in France, Belgium, Holland, and Germany.

The work of the department, for the present, consists of investigating and reporting on the efficiency of the combustion of fuel in the various plants of the organization and making recommendations for improvements in the combustion apparatus or its operation. It has not yet been extended to include drastic changes in the apparatus, such as the substitution of one fuel for another, but it is expected that such problems will be attacked after the more obvious alterations have been adopted by fuel consumers. The engineers of the department visit plants which ask for their services and make all necessary tests to determine their efficiency. A charge is made for this work by the department, which amounts to approximately one-half the expense of the investigation, the rest of the expense being borne by the federation. The results of each investigation are communicated in a report to the company concerned and are also placed in the files of the department of fuel research. In the latter case the data

only are filed, the name of the company or plant to which they refer being kept secret.

Another important duty of the department is the education of stokers and managers by personal contact and by publications. There is published a quarterly periodical, *The Fuel Economy Review,* which contains interesting articles regarding the department's investigations as well as articles from independent sources on combustion problems. There are also issued special pamphlets, handbooks and charts from time to time, for the information of plant managers and workers in boiler rooms. All these publications are circulated free of charge to the members of the federation and extra copies may be bought at a nominal figure.

Where Wastage of Heat Frequently Occurs in Steam Boilers



1. Avoid Wastage of Cinders in the Ashes by Cleaning the Fires Carefully and by Using Suitable Firebars.

2. Avoid Production of Black Smoke and Incompletely Burnt Gases by Regularly and Frequently Firing Coal in Small Quantities. Keep a Proper Depth of Fire

3 Regulate the Draught by the Damper to Reduce the Excess Air. Try to obtain 12% CO_2 in the Chimney Gases.

4. Keep the Grate Properly Covered with a Level Fire. Use the Rake when Necessary for this Purpose.

5. Examine the Boiler Setting Carefully for Air Leakage Particularly Furnace Doors Cracks in the Side Walls, Joints Between the Boiler Shell and Brickwork and the Damper Slides

6. Keep the Boiler Surfaces Free from Soot and Flue Dust

7 Keep the Internal Boiler Surfaces Free from Scale.

8. Do not Force the Boilers Unnecessarily.

9. Examine the Seating Blocks and Partition Walls Carefully. Repair if Necessary to Avoid Bypassing

10. Lag the Exposed Surfaces of Boilers and Steam Pipes Efficiently.

11 Avoid Excessive Blow Down

12. Keep the Boiler Filled to the Working Level by a Continuous and Steady Feed

13 Avoid Leakages of Steam from Boiler Fittings and Valves

Fig. 5—A diagram indicating the principal sources of loss of heat in steam-raising for the guidance of boiler-house staffs, issued by the Fuel Economy Department of the Federation of British Industries.

The fuel economy department believes that smoke abatement is only a question of efficient use of fuel and that, with such efficient use, smoke will entirely disappear. It is also of the opinion that the only possible way of making efficient combustion the rule rather than the exception, as it is now, is to educate plant managers to the truth that a saving in money can always be made in this way, and the fireman to the well-known methods of efficient combustion. It believes that, in the present condition of industry, any attempt to pass new laws or to enforce more rigidly those already in existence will be abortive. On the other hand, it is possible by proper education practically to eliminate the smoke nuisance.

The department is not aware of any new devices for smokeless combustion which are of importance, because those already known will produce practically perfect combustion if they are rightly used. It is more important to put emphasis on the adoption and proper use of well-known appliances than to try to develop new ones.

Activities of Educational Institutions.

All the universities in the industrial districts and those which have students interested in industrial work, such as the University of Glasgow; Armstrong College, Newcastle; the University of Manchester; the University of Leeds; the University of Sheffield; and the Imperial College of Technology, London, have strong and well-equipped fuel departments, where smoke abatement and combustion efficiency are considered as part of the study of fuel. These departments are headed by able men and their laboratories are provided with apparatus for the study of combustion problems.

All these universities conduct night schools in which men who work in the daytime may carry on their studies under competent supervision and may receive the same

degrees as the men who can devote their whole time to study. The courses of the fuel departments are among the most popular in these night classes. Some attempts to hold classes for the instruction of stokers have been made in the universities.

Extensive research programs are in operation which include problems in efficient and smokeless combustion. Armstrong College is specializing on work on mining problems, such as flotation for the production of a more valuable fuel. The University of Sheffield is interested in flame and its propagation, coal-dust firing, and distillation. The University of Leeds works principally on problems connected with gas. The University of Manchester is carrying on a great deal of work on efficient combustion of various solid fuels in different types of domestic appliances and on the composition and possibilities of the distillate from low-temperature carbonization. The Imperial College of Technology is working principally on fundamental problems concerning the composition of coal and the reactions which occur in distillation and combustion.

MEASUREMENT OF ATMOSPHERIC POLLUTION

Systematic measurement of atmospheric pollution is carried on throughout the United Kingdom by the Advisory Committee on Atmospheric Pollution of the Meteorological Office. As mentioned on page 15 of this Bulletin, this committee has developed certain forms of apparatus for making the measurements. All this apparatus is more or less in process of development and is not entirely perfected, but measurements can now be conducted in a routine manner and data of much value are being obtained. Descriptions of the three principal forms of apparatus are given below.

THE STANDARD GAGE FOR DETERMINING SOOT FALL.

This gage consists of a galvanized iron stand, which supports a circular enameled iron vessel, with a 4-ft. square opening. Projecting above the vessel is a wire screen, open at the top, which prevents birds from settling on the vessel. The vessel is conical at the bottom and communicates by means of a copper tube with a bottle of sufficient size to hold one month's rain fall. The rain and deposited matter falling in the vessel are collected in the bottles and removed once a month for analysis. Some trouble has been experienced from chipping off of the enamel and corrosion by weather. While this has been overcome partially by the use of a special varnish which withstands the action of weather quite well, it is believed that the apparatus may be improved by the use of glass instead of enameled iron.

The gage is placed on the ground level, in an open space free from abnormal dust. Before removing the bottle the vessel is washed down with some of the collected water, to remove any adhering matter. The deposit is analyzed for the following:

UNDISSOLVED MATTER	DISSOLVED MATTER
Tarry Matter	Loss on Ignition
Ash	Ash
	Sulphates
	Chlorides
	Ammonia
	Lime
	Acidity
	Alkalinity

A complete description and instructions for setting up the gage and analyzing the deposit are contained in a publication of the committee. There are 30 of these gages in operation in various parts of Great Britain. The results obtained from them are expressed in metric tons per square kilometer, per month, and are published periodically by the central committee.

Fig. 6.—The standard gage for the determination of dust fall (the Meteorological Office Advisory Committee on Atmospheric Pollution in Great Britain). The height from the ground to the top of the gage vessel is 4 feet.

Measurements by this method are, of course, subject to errors and can only be approximate at best, but they furnish data regarding the dust fall which are regarded as satisfactory. The method is also quite easy to operate. The complete apparatus may be purchased from C. F. Casella & Co., Ltd., 49 Parliament Street, London, S. W. 1, England, at a cost of about $30.00.

Below is given a tabulation of average results for different parts of Great Britain, for the years ending April 1, 1915, 1916, 1917, 1918, 1919, and 1920, and, for comparison, figures made by a somewhat different method in Pittsburgh during 1912 and 1913.

DUST FALL

METRIC TONS PER SQUARE KILOMETER PER MONTH

Year Ending April 1	1915	1916	1917	1918	1919	1920
Birmingham	14	11	....	....	....	....
Bolton	22	17	....	....	....	....
Exeter	9	8	....	....	....	....
Kingston-on-Hull	14	13	....	....	....	....
Leicester	....	15	12	14	....	....
Liverpool	19	19	....	....	....	....
London	13	15	14	14	13	11
Malvern	2	2	3	3	....	3
Manchester	15	16	17	12	15	....
Newcastle	16	17	23	21	17	15
Oldham	31	31	....	....	....	....
Rochdale	....	....	24	35	30	30
Rothamstead	....	....	....	....	....	4
St. Helens	....	....	....	20	18	14
Sheffield	13	....	....	....	....	....
York	9	9	9	....	....	....
Southport	....	....	....	....	7	6
Coathbridge	8	10	13	16	17	....
Glasgow	16	13	12	14	13	10
Greenock	10	13	15	....	....	....
Leith	8	10	....	....	....	....
Paisley	16	....	....	....	....	....
Stirling	11	....	....	....	....	....

PITTSBURGH (1912-13)

Cargo School	Ohio Valley School	Allegheny High School	Oliver Bldg.	Irene Kaufmann Settlement	State Hall, U. of P.
17	57	19	48	47	28
Peebles School	Ormsby Park	Colfax School	Brushton School	Arsenal Park	Margaretta School
24	27	22	21	29	20

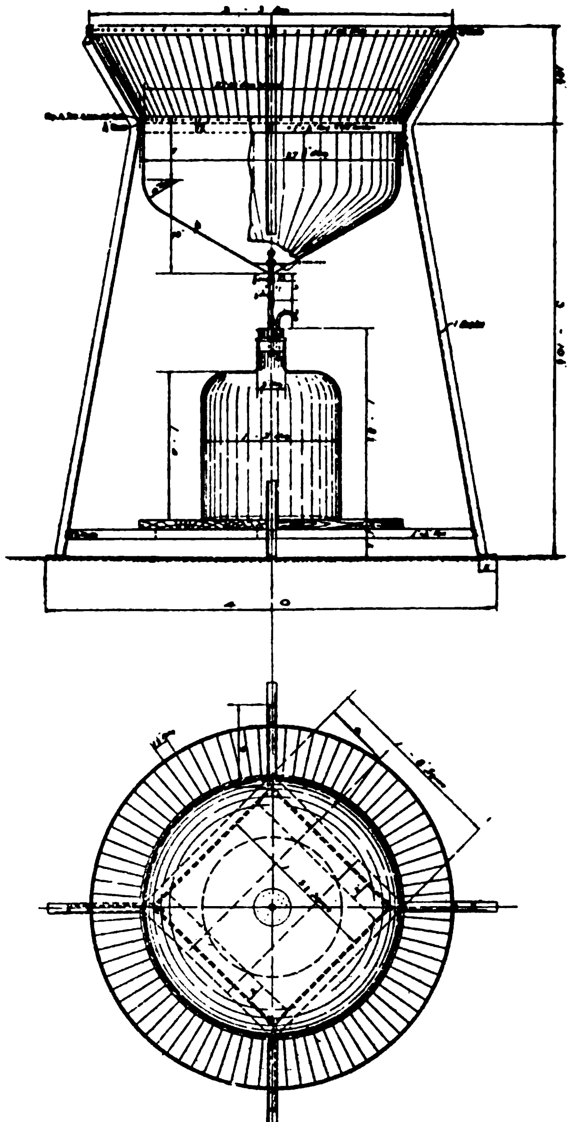


Fig. 7.—Details of the standard gage of the Meteorological Office Advisory Committee on Atmospheric Pollution.

The maximum fall in England, according to these figures, is in certain towns in the Manchester district—for instance, Oldham and Rochdale, which are cotton and

wool manufacturing centers. It is to be noted that the data for Sheffield are given for only one year and that no figures are given for Leeds. Both these towns have been observed to be very dirty, Sheffield being polluted with smoke from the steel mills, and Leeds from the cloth factories and engineering works. The mining center of Newcastle and the industrial center of Manchester both show quite high results, with some improvement during later years. Glasgow shows high results at the beginning of the investigation, but has apparently been cleaned up to a certain extent. The amount of dust fall in these towns is in great contrast to that in Malvern, which is a rural and vacation community where the air is practically unaffected by industry. Southport also is quite free from excessive deposit, being situated in an agricultural and residential district, although not far from London.

The figures for Pittsburgh obtained by the Smoke Investigation conducted by the Mellon Institute were very much higher on the whole than those for England. This is probably due, to some extent, to the different forms of apparatus used for measurement, but they show that Pittsburgh was very dirty at the time the measurements were made. As a result of the Institute's Smoke Investigation, conditions in Pittsburgh are now very different. If measurements were made at the present time, it is believed that they would show a comparison very favorable to Pittsburgh.

Automatic Air Filter.

In this apparatus an aspirating vessel is provided, into which water is admitted through a regulating cock at the bottom. A siphon is fixed inside the vessel, which causes the water-level to oscillate at regular intervals between two fixed levels in the vessel: thus, while the water is rising, air is driven out of the vessel; and while it is falling, air is aspirated into the vessel.

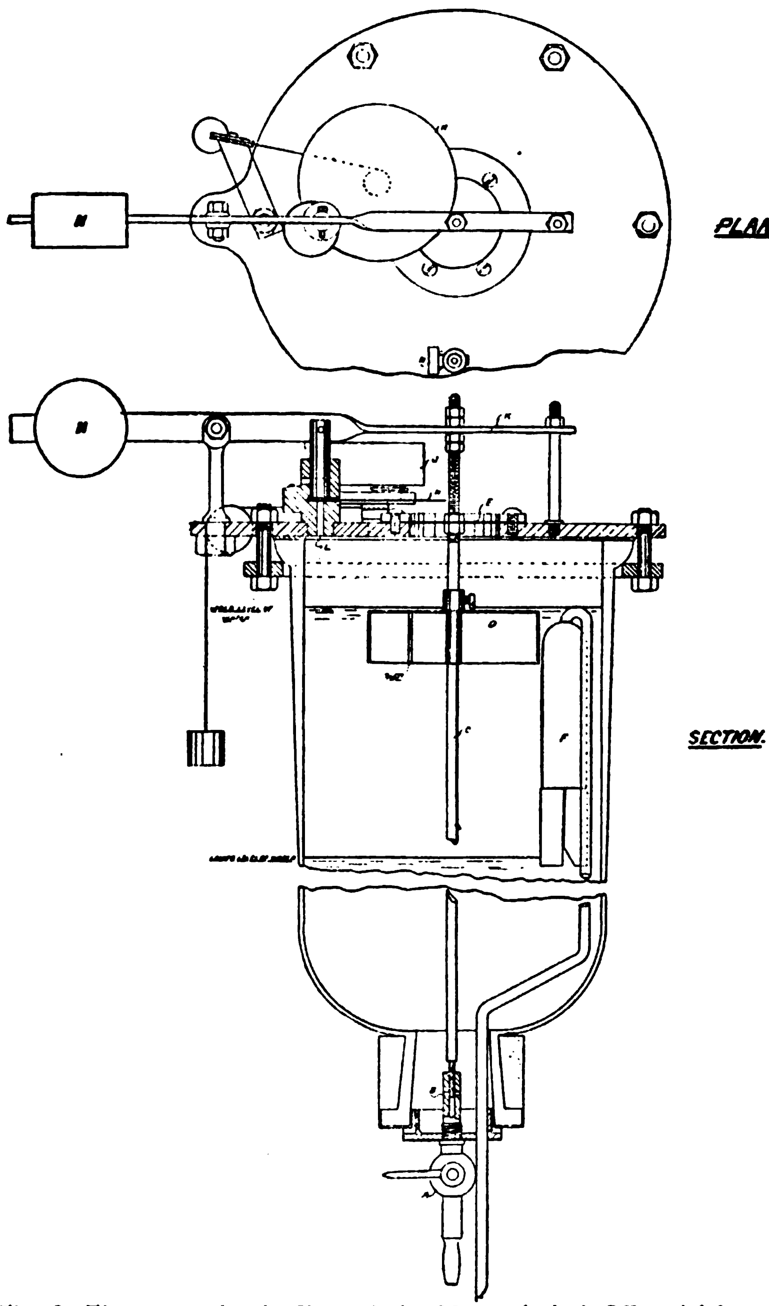


Fig. 8—The automatic air filter of the Meteorological Office Advisory Committee on Atmospheric Pollution.

On the top of the instrument, an entrance of fixed diameter is provided for air, over which revolves a disc of filter-paper. This disc is locked between two plugs, on the lines of the single-record filter, during the time air is being drawn into the vessel. The disc is caused to revolve by a weight and string, but the rate of its revolution is regulated by a stop which follows the hour hand of a small clock placed above the disc. The force for clamping the disc is obtained from a pressure-operated, flexible diaphragm acting through a lever. The records are made upon a disc of paper, upon which the hours have already been marked, similarly to a clock-face, and each record is placed automatically opposite the time at which it is taken. Thus the interval between records is unimportant, although, as will be shown below, this is easily adjustable. The present instrument takes a 24-hour disc. A detailed description of the apparatus and method of operation is given in the fourth report of the Advisory Committee on Atmospheric Pollution.

The record which this instrument gives consists of circular spots of various depths of shade appearing in the perimeter of a filter-paper, as described, the total perimeter of which represents a 24-hour day. The record spots are accurately timed in the perimeter. A quantitative measurement of the concentration of dust in the air is obtained by comparing the color of these spots with an ingeniously arranged standard, which is described in the sixth report of the committee.

This apparatus is open to the objection that its measurements depend on the color of the suspended dust particles; and, since the color of the particles must vary to a certain extent, it cannot be absolutely accurate. But it is the closest approach so far obtained to an automatic record of the amount of dust in the atmosphere and its results approximate a quantitative measure of this con-

centration. It is therefore a useful apparatus. The records show very plainly the number of foggy days as compared with the number of clear days, the exact time of duration of the fog and its relative density. By a comparison of the shape of the average curve for work days, on which industrial furnaces are operating, and for Sundays, when they are closed down, F. S. Owens comes to the conclusion that, in London, the domestic fires are responsible for something over two-thirds of the domestic smoke. Curves are presented herewith which show the average hourly concentrations of dust in the atmosphere at London, on foggy and clear working days, Saturdays and Sundays.

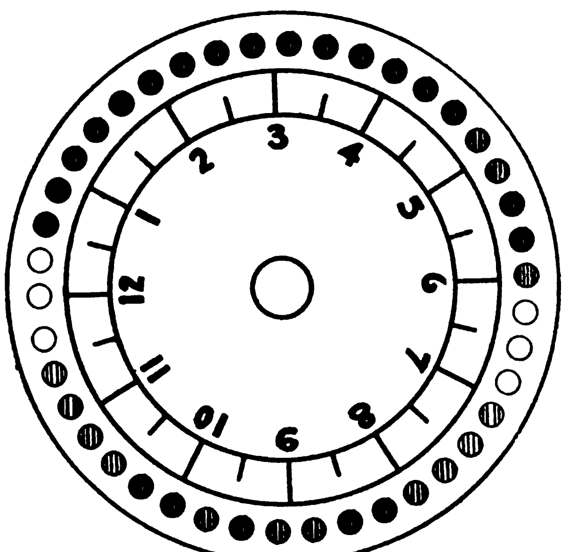


Fig. 9.—The 12-hour chart from the automatic air filter of the Meteorological Office Committee. The actual records consist of a uniform film of deposit, the shading in the diagram giving an idea of the variations of intensity.

The apparatus has only been in use for about a year and no dependable figures are as yet available for other parts of Great Britain, but it is being tried in different sections of the country and the data will be published dur-

ing 1923. The normal quantity of suspended impurities in the air of London during the daytime in winter is approximately one milligram per cubic meter. The amount increases during a fog to about four times this quantity. The curves show interesting variations with the course of human activity during the day. This apparatus may be purchased from C. F. Casella & Co. for about $135.00.

INSTANTANEOUS AIR SAMPLER.

This is an apparatus for making an instantaneous determination of the amount of suspended matter in the air by microscopic observation of a cover glass on which the suspended particles from a sample of air are precipitated. It consists of a small hand suction-pump, which draws the air sample through a slit, 0.05 mm. wide and about 5 mm. long, in the floor of a cell, the roof of which is a microscope cover glass placed a few mm. above the floor. In passing through the slit, the air is cooled sufficiently to deposit moisture on the dust particles which strike the cover glass and, being damp, adhere to it. A measurement takes less than one second and the determination of the result is made under the microscope in a very few minutes. After being drawn, the samples can be held indefinitely before the microscopic examination.

The method has been tested quite thoroughly for errors, such as incomplete precipitation of the dust particles, and these errors have been found to be less than 10 per cent. of the total result. This apparatus is invaluable for investigations of the area and height of fogs and other conditions where an instantaneous sample is useful. It is now being manufactured by C. F. Casella & Co.

PART II.

THE LOW-TEMPERATURE CARBONIZATION OF COAL

THE LOW-TEMPERATURE CARBONIZATION PROCESS

Low-temperature carbonization should produce: (a) a rich gaseous fuel which would be more valuable per heat unit than coal because of its greater flexibility and convenience; (b) an oil distillate, also more convenient than coal as a fuel and with some possibilities, as yet incompletely explored, for other uses which would make it still more valuable; and (c) a solid fuel which will ignite easily and burn smokelessly to completion in ordinary combustion appliances, with no expert attention. As compared with high-temperature by-product coking, it has the disadvantage of requiring practically as complicated machinery for the process and nearly as much heat, while the yields of the more valuable constituents of the oil and gas are less.

This process has been considered in England for many years. It has had a rather unfortunate history in that several companies have been formed whose main idea was the flotation of stock without regard for the possibilities of the process, except so far as it influenced the sale of stock. At the same time, much valuable experimentation has been done and various processes which approach commercial values have been developed.

At present there is no subject in connection with smoke abatement and fuel economy which is receiving as much attention as this one. Nearly every individual or organization interested in these questions is working on

some scheme for the purpose of studying its possibilities. The influential members of smoke abatement societies, government officials, officials of smoke-making companies, the universities and other students of the subject agree that this process offers the best possible chance at present of stopping the smoke nuisance. There are several different methods proposed on which experimental work has been done and which offer some promise; these are described *infra*.

THE PROCESS OF LOW-TEMPERATURE CARBONISATION, LTD.

The process which has attracted the most attention, probably deservedly, is that of Low-Temperature Carbonisation, Limited, Cockspur Street, London. This organization has recently changed hands and is now properly Low-Temperature Construction, Limited, but is usually referred to under the older name. Experimentation has been carried out by this company in several different types of apparatus and at several places. At present a plant is operated at Barugh, near Barnsley, which handles about 36 tons of coal per day and is said to be able to operate on a commercial basis. It is not doing so at present because experimenting is being carried out on another process which is closely allied to low-temperature carbonization.

The process has never made any great amount of money; and since it is in a field where unscrupulous persons have often exploited the public and it has been necessary for the company constantly to raise money to continue experimental work, it is said in some quarters that those in charge know that it will never operate on a sound basis financially, but is only being run as a stock-selling scheme. However, the opinion of several technical men who are not directly connected with the company, but who

Fig. 10—A general view of the retort house of Low-Temperature Construction, Ltd.

have had an opportunity to keep in touch with it, is that the owners are fully convinced that the process will be a valuable one and that the probabilities are that they will not be disappointed.

The process may be described briefly as follows:

Coal of about the fineness of ordinary slack is heated for eight hours in a retort and then cooled for the same length of time in a cooling chamber. The coal used is a mixture of about 70 parts of non-coking slack and 30 parts of coking slack. This mixture is washed until the ash is reduced to 5 per cent. or less, the volatile matter being about 35 per cent.

The slack mixture is first conveyed into a measuring hopper, which contains 1200 lb., the right amount to charge one retort. This hopper stands above the retort, into which the charge is admitted through a rotary valve. The retort is built of fire-brick and is heated by a gas flame in somewhat the same manner as a high-temperature coking retort. It is about 7 ft. long, 9 ft. deep and 11 in. wide, tapering slightly from bottom to top, to help in dropping out the charge. In the center hang two perforated cast-iron plates with a space between them, to allow the passage of the distilled vapors and to allow the plates to collapse and thus loosen the charge when carbonizing is finished. These plates are operated by an ingeniously designed toggle-joint. This collapsing increases the width (3 in. to 4 in.) of each side of the retort, thus overcoming one of the chief difficulties of low-temperature carbonization processes, that of adherence or sticking of the charge. It is also said that conducting the gas through the passage between the plates prevents the deterioration which takes place in it when it must pass some distance through the carbonizing mass. The width of the charge as it lies against each wall, 3 in., is about the maximum for good heat transfer and it produces a slab of a convenient size for handling.

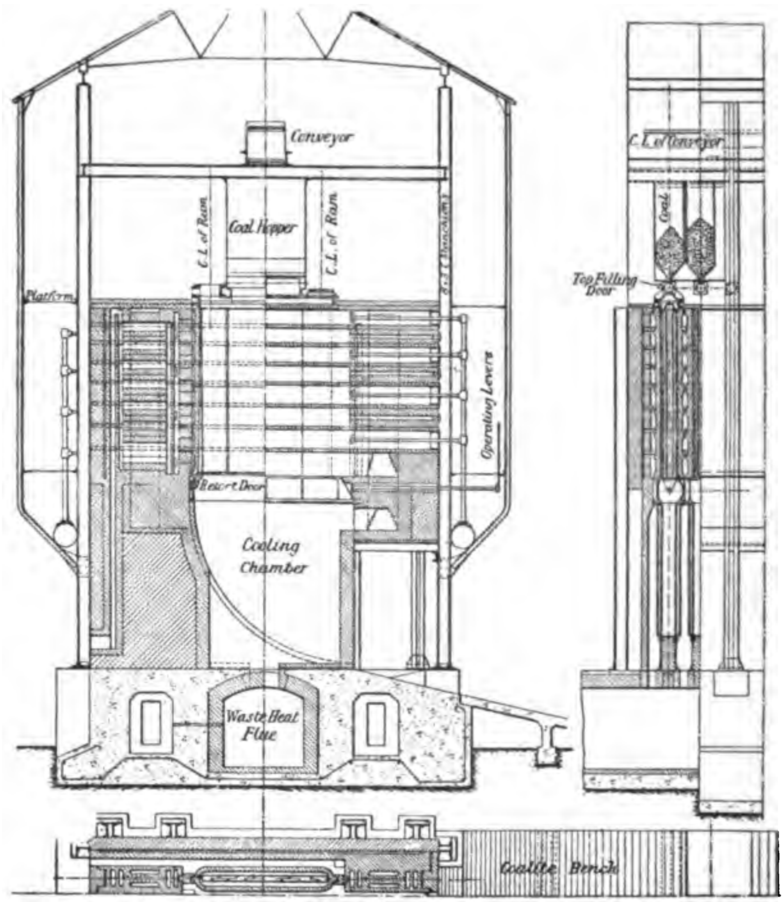


Fig. 11—A cross-section of the retorts of Low-Temperature Construction, Ltd., at Barugh.

The retorts are built as nearly as possible gas-tight, and the gas is drawn off through a swan-neck by positive pumps at a low and carefully controlled vacuum, which prevents leaking in either direction. A small amount of steam is admitted into the retort to increase the yield of ammonia.

After heating for eight hours at about 600° C., a just-visible red heat, the center plates are collapsed and the carbonized charge, which is now in the form of two slabs, 3 in. thick, is dropped through a rocking cylindrical valve into the cooling chambers.

The cooling chambers are fabricated from boiler plate and are surrounded by water-jackets. Each retort feeds one chamber, which is of the same capacity as the retort. The cooling chambers have a sloping floor which throws the charge toward the front side, which is removable and serves as a door for discharging. The waterjackets are baffled so as to enable hot water to be drawn off at the top for use in generating steam for fractionating the tar oils. It was necessary to develop these cooling chambers because if the coke were discharged direct into the air it would catch fire. Drawing through a water-seal or quenching destroys the value of the fuel, since it causes it to break up and throw dangerous sparks when burned in an open fire. The coke is cooled sufficiently for drawing in about two hours, but is usually left in the cooling chambers until time to drop the next charge. It is raked out after removing the front of the chamber.

The product is a semi-coke containing about 10 per cent. of volatile matter. It burns freely and, like good bituminous coal, may be readily burned in an open fire. According to tests made by Dr. Fishenden, it gives out a higher percentage of its total heat as radiant heat than coal does and is therefore more valuable as a domestic

fuel. It is comparatively light but strong, and stands shipping well. The original slabs, 9 ft. x 7 ft. x 3 in., are broken to convenient size before shipping. One ton of slack produces about 1,400 lb. of fuel. The other products from 1 ton of coal are 6,000 cu. ft. of 700 B. t. u. gas, and 20 gal. of heavy oil. This oil may be burned as it is or may be fractionated for its more valuable products. Its real value has not yet been determined, but it contains a much higher percentage of unsaturated compounds than ordinary mineral oil. Naphthenes and resins are present in large proportions and there are some phenols. A much smaller amount of ammonium sulfate is produced than in the high-temperature process.

It is to be noted that this process is working on a slack which is very cheap and is also capable of being washed quite free from ash. A more expensive or higher ash raw material would increase the cost of the resulting fuel. The range of coals to which the process might apply has not been fully determined, but it can probably be made very wide by working with the proper mixtures.

THE MacLAURIN PROCESS

The method of internal carbonization is particularly characteristic of the MacLaurin process, which, in fact, differs from all others in having no external heating at all, not even steam.

The oil is of peculiar composition. It is similar to low-temperature oil in that it has no naphthalene and anthracene, but differs in having no light oils, although there is present a very high percentage of cresols and xylenols, up to 50 per cent. of the total oil, and including an exceptional amount of high-boiling phenols. The crude oil can also be used directly as fuel oil.

The composition of the gas is 16.0 per cent. CO, 13.0 per cent. CH_4, 16.1 per cent. H_2, 6.2 per cent. CO_2, and 48.1 per cent. N_2. No hydrocarbons except methane are present, because the oils are not "cracked" during the process of carbonization. The yield of ammonium sulfate is 24 lb. per ton, the ammonia liquors being free from ferrocyanides and sulphocyanides, but containing di- and tri-hydroxy phenols.

The further yield by this process from 1 ton of coal (12,300 B. t. u.) with 35 per cent. of volatile matter and 7.7 per cent. of water, is 1,096 lb. of residual smokeless fuel, 15.6 gal. of oil and 27,731 cu. ft. of gas at 247 B. t. u., the total loss in the whole process being 11.3 per cent. of the coal. It must be pointed out, of course, that in comparison with other processes these figures must be increased by about 15 per cent., since no external producer gas is required.

THE NEILSEN PROCESS

In the Neilsen process slack is fed into a revolving drum. At the outlet the larger part of the slack is drawn off and briquetted, and a small portion drops into a furnace and is burned there. The hot gases from the furnace pass back into the drum and furnish heat for the distillation. The combustion in the furnace is controlled so that the resulting gas is high enough in calorific value to be commercially salable. The process is somewhat complicated and has not been worked commercially.

THE PROCESS OF THE DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

In this process, a mixture of slacks from different sources is charged into a muffle furnace in trays and there carbonized. The muffles are fabricated from boiler

plate and are 4 ft. wide by 8 ft. long by 1 ft. high, with convex top and bottom. Nine muffles are built side by side in a furnace heated by gas burners in the roof. The retorts lie on the bottom of the furnace.

The trays in which the slack is charged are divided into sections, so that, after carbonizing, the fuel comes out in rectangular briquets, about 8 in. long by 4 in. square. The carbonizing requires about eight hours.

Successful operation depends on the use of a coal of exactly the right properties. It must coke sufficiently to produce a solid block, but it must not swell enough to destroy the trays. It must shrink during the last stages, to loosen itself in the trays and thus permit easy removal. There are only a few coals which fulfill these requirements completely, but, by making the proper mixtures of two or more coals, the range which may be used is very wide.

The Department of Scientific and Industrial Research has developed a laboratory test which enables the determination of the results to be expected from any given mixture. This test consists practically of low-temperature coking on a laboratory scale, with determination of the amounts of gas and oil obtained.

By this process about 1,400 lb. of coke, about 300 cu. ft. of gas of 900 B. t. u., and 14 to 15 gal. of oil are produced from a ton of coal.

LOW-TEMPERATURE CARBONIZATION APPLIED TO THE MOND PROCESS

Some new and interesting information is contained in a paper submitted by the Power Gas Corporation, Ltd., which company has been using the Mond process for the past 30 years. In the original Mond process it was possible, using cheap slack containing 1.3 per cent. of nitrogen, to recover ammonia to the extent of 65 to 75

per cent. of the total nitrogen, equal to 85 to 95 lb. of ammonium sulfate per ton of coal, with a yield of gas of 135,000 cu. ft. It was necessary, however, to add to the producer a very large amount of steam, about 2.5 tons per ton of coal, one-third of this steam being decomposed in the producer, and two-thirds passing away in the gas, which left the producer at about 925° F. About 0.75 lb. of the steam is recovered, however, so that a net amount of 1.75 lb. of steam per lb. of coal is required. This process has no longer the great economic advantages in Great Britain it formerly had, because the prices of labor, coal and sulfuric acid have increased out of all proportion to the price of ammonium sulfate.

Consequently, the Power Gas Corporation, Ltd., has altered the original Mond process with a view to increasing both the economy and the efficiency, and now combines with it the principle of low-temperature carbonization. This new process, that of Beswick and Rambush, consists in converting as much as possible of the volatile matter of the coal into liquid products according to low-temperature methods, while the residual fuel is entirely converted into producer gas. The transmission of heat to the charge of raw coal in the upper part of the producer is claimed to be achieved in a gradual but effective and rapid manner by the employment of the sensible heat contained in the hot producer gas evolved in the lower part of the producer. That is to say, the raw coal charged into the producer is kept in the upper or primary zone at such a temperature as to get a low-temperature carbonization with the maximum yield of oils, and the residual fuel is then converted into producer gas in the lower or secondary zone. At the same time, the very high yield of ammonium sulfate, 90 lb. per ton of coal, characteristic of the original Mond process, is retained, and the whole operation is carried out in one

simple plant which is comparatively cheap to erect. The steam required in this new process is only about 1 lb. per lb. of coal carbonized. Also, nearly all this steam is decomposed, and the saturated air blast no longer requires to be superheated. The gas evolved has an average composition of 21.0 per cent. CO, 20.5 per cent. H_2, 8.3 per cent. CO_2, 4.9 per cent. CH_4, and 45.3 per cent. N_2, with a net calorific value of 178 B. t. u. per cu. ft. The yield of gas is 115,000 to 120,000 cu. ft. per ton, and the quality is very nearly as good as the ordinary hot producer gas. The amount of low-temperature tar or oil produced is about 15 to 24 gal. per ton.

Additional advantages claimed for the new process are that, because of the lower temperature in the producer, the pipe lines are smaller, the maintenance costs are reduced, and the capital outlay and ground space are both much less because of the elimination of the air and steam superheaters. Also, the plant is so arranged that the amount of either tar or ammonia can be easily manipulated, depending on the market.

OTHER PROCESSES

Various other low-temperature processes have been suggested and tried. One of these consists in spraying finely-divided coal into an internally heated tower and admitting enough air to keep up the heat. The resulting product is briquetted for fuel. Another procedure is to blow finely-divided coal through a heated bath of molten lead.

The "pure coal briquet" (Sutcliffe-Evans) process consists in roughly pulverizing the coal and mixing it with about 20 per cent. of pulverized coke breeze or other product from the carbonization of coal. This mixture is then briquetted in a special briquet press at a very high pressure, 10 tons to the square inch, giving perfectly hard

briquets without the use of a binder, such as pitch. These briquets are now carbonized by means of producer gas at high temperature, say 1,600° F., the heated inert gas passing through the mass of the briquets in a simple type of retort which is merely a vertical cylinder. These briquets have the remarkable property that they do not expand on carbonizing, so that existing gas-works or coke-oven retorts can be used. Also, although the residual fuel contains only about 2 per cent. of the volatile matter, it is easily ignited like ordinary raw coal, because of the peculiar fine grain structure which, under the microscope, is seen to resemble charcoal.

Part III.

Other Developments in Fuel Technology

COMBUSTION IN STEAM-RAISING PLANTS

A recent survey of the steam-boiler plants of the United Kingdom, made by David Brownlie, shows that 50 per cent. of the coal burned is used for raising steam. 250 boiler plants were investigated and the conditions under which they operate determined. The boilers are of various types, selected so as to be representative for the country. Fuel is burned at the rate of about 21 lb. per square foot of grate surface per hour. Less than 5 per cent. of the fuel is bought on analysis or scientific specification. The average fuel affords 11,800 B. t. u. per pound and contains 11.5 per cent. of ash. The B. t. u. value varies from 7,000 to 14,000. Hand-firing is used in 76 per cent. of the plants, with 58 per cent. efficiency, and mechanical-firing in the rest with 61 per cent. efficiency. The average efficiency of all is about 60 per cent. The average amount of water evaporated per pound of coal is 6.6 lb. Forty-nine per cent. of the plants operate on chimney draft only, 37 per cent. use some form of steam jet as an aid to chimney draft, and 14 per cent. induced or forced draft. Six per cent had CO_2 recorders, 26 per cent. were operating with very little smoke, 55 per cent. were making a fair amount of smoke, and 19 per cent. were making a great deal of smoke.

Visits were made to four of the best boiler plants in the country, two in London, one in Glasgow and one in Newcastle, and the details of their boiler room practice investigated.

Chain-grate stokers were in use in all the plants and in some there were underfeed stokers, and also side-feed and sprinkling types. The chain-grate type was considered

the best by all, as the result of careful comparisons of the various types.

All stokers were covered for several feet on the feed-end by a fire-brick arch, to promote ignition of the coal and to force the partially burned gases into the hottest part of the furnace. In the most efficient plant a good deal of experimenting is being done with these arches. It has been found that, for the best combustion, a different height and shape of arch is necessary for each type of coal burned. The proper curve for the arch, as well as the slope, depends on the coal used. Some good results have been obtained by producing eddies under the arch, in one case by making the slope convex instead of regular, and in another by building it in steps instead of with a regular slope. The value of these modifications also depends upon the coal.

Balanced mechanical draft was used in all the plants; that is, fans were used either for induced or forced draft or for both at the same time. In three cases the plants were operating with either forced or induced draft—in the most efficient one with balanced draft. The chain-grate stokers in most cases were fitted with draft-boxes, with dampers for adjusting the draft to different strengths at different zones of the fire.

All the plants were fitted with CO_2 recorders, water and steam meters, draft gages, and pyrometers. In the most efficient plant the CO_2 recorders were not in operation, and it was stated that skilled control by the firemen was more accurate than the best recorder. It was suggested here that if these recorders are to be of use a type should be developed which is very much more accurate than the present. Recorders which depend on electrical changes in the gas are becoming popular and are giving good service. Accurate records of the operation are kept in all these plants.

A great deal of attention is paid to the personnel of the firemen. A man is never engaged for this job unless he can show evidence of considerable experience and knowledge of the work. The wage of these men is very little—in fact, less than that of the engine drivers.

In one plant the air for combustion was preheated by the exhaust gas, and in two plants cooling air from the turbines was used. One plant had a traveling feed which distributed the coal evenly along the stoker, instead of piling it deeper at the center. In three the coal was dampened before firing, to make the fuel bed porous. One plant had forced draft fans built in the ends of the stoker-drive, where they take up much less room than ordinarily and can be of much smaller size. This plant also used an ash conveyor wherein the ash drops directly from the stoker into a trough of water which serves as a seal against draft leaks. The ash is carried out on belt conveyors. This contrivance requires comparatively little room under the boilers.

Three of the plants operated with a plainly visible smoke haze at the top of the stack. This haze was considered necessary to insure against the presence of too much excess combustion air. In the fourth and most efficient plant the haze was much fainter, being barely visible from a little distance.

COAL-DUST FIRING

The development of coal-dust firing in England is largely along the lines of small "unit" pulverizers. Such pulverizers were inspected in operation at Price's Candle Factory, Battersea, and the Edgar Allen Steel Works, Sheffield. These pulverizers are of the "Turbo" type, their capacity running from 500 lb. to 2 tons per hour. The pulverizer and burner together form one unit which operates one furnace. The machines were operating with little attention, the furnace conditions were good and the

atmosphere was comparatively clean. It is claimed that the excess air is less than usual and that complete combustion can be obtained with 20 per cent. excess.

Coal in the form of "smalls," commercially dry, is fed into a hopper at the top of the machine. This coal goes through an adjustable feed into the pulverizer, which consists of a series of spiders or beaters turning at high speed in a baffled cylinder, pulverizing the coal and acting as a blower for the burner. There are air-inlets in the intake and outlet of this pulverizer for use in controlling the fineness of pulverizing, which varies according to the speed of passage of coal through the pulverizer. From the pulverizer the dust and air mixture is blown into the burner, which is simply a straight tube with provision for controlled air-injection around it. A 16-horsepower motor is used in the 500-lb. pulverizer, which normally would consume about 8 horsepower. The coal burned may be easily adjusted to a small fraction of the capacity of the machine, and a wide range of fuel may be used. The lower volatile materials, such as gas-house coke, operate successfully only after the furnace is well warmed up on more free-burning material.

Unless some device is used to separate the ash from the burned gas, a large part will go into the flues and the atmosphere. At one furnace which was inspected, only about 200 lb. of ash were being taken out of the ash-pit for 15,000 lb. of coal burned. In other words, 75 per cent. or more of the ash was being driven out into the atmosphere.

If this occurs in a boiler, the ash deposit on the tubes reduces the evaporation efficiency, and for successful operation one of two devices is used: (a) the combustion chamber is so shaped that the gas, containing ash, comes in contact with a very hot floor, where the ash melts and is drawn off as slag; or (b) at a point where the direction

of flow suddenly changes, the gas comes in contact with a little cold air, which chills the ash, causing it to agglomerate and settle out.

These burners allow smokeless combustion in some places where it would be difficult otherwise; but, unless provision is made for separating ash, a nuisance may be produced by its emission from the stack.

GAS DEVELOPMENT

The opinions of several authorities in the universities and of the leading consulting gas engineers were obtained. However, the evidence on this question was somewhat conflicting.

The producing gas companies and the engineering firms manufacturing apparatus for their use have been doing considerable advertising and propaganda, looking toward a more extended use of gas for domestic and industrial purposes. This work is resulting in an expansion of the industry and a corresponding decrease in coal smoke, and the interested parties think that the expansion will continue. They believe that it would be practicable to put almost all the coal used in Great Britain through gas retorts, replacing the bituminous coal now used by gas in some cases and by gas-house coke in others. Authorities who are in a more neutral position, such as the heads of university fuel departments, think that the possibilities along this line are being somewhat overstated. In their opinion the possibilities are greater for low-temperature carbonization processes. The gas engineers think that gas-house coke, if carefully made, will be entirely satisfactory in most places where a low-temperature coke would be used. This would include burning in open fires.

Progress by the manufacturers has been stimulated by recent changes in the legal standards for gas. These

changes include the removal of specifications for luminosity of the gas and provide for the sale of the gas at a price calculated on the actual heating value rather than the number of cubic feet. The price is a stated amount per "therm," a "therm" being 100,000 B. t. u. This makes possible the manufacture and sale of a gas of either low or high calorific value without hardship either to the manufacturer or the consumer. The luminosity of the gas is, of course, an outgrown specification.

These changes enable the gas companies to go forward with developments with a much freer hand than formerly. The old-fashioned horizontal retorts are being replaced by vertical retorts and it is becoming common practice to introduce steam into these retorts. Some companies do this simply to increase the yield of gas under sudden or unusual demand. Others do it as a matter of common practice. In either case, it is more efficient than making water gas separately and mixing with coal gas, both because of the simple apparatus and greater heat efficiency. In some cases, this steaming has been carried to complete gasification of the coal, but this produces a gas which is too low in calorific value and loses valuable by-products.

A process which has met with some success as an alternative to water-gas production is a complete gasification conducted in a double retort, the carbonization being done in the upper portion which discharges the coke into the lower, where the gasification takes place. This produces a gas which is valuable as an addition to the coal gas. It has not proved commercially practicable to replace the vertical retorts with this process.

Another line of development is the use of oxygen gas instead of air to furnish the heat for gasification. This would give a producer or water gas with much higher calorific value. The process depends for success entirely

on a cheap method for producing oxygen in large quantities, and it is believed that such a method is being developed.

COAL RESEARCH

It is natural that a large amount of research should be done on coal in England. This investigational work includes the mining, distribution and use of coal. An important part of this research is its application to smoke abatement, the problem of which is constantly in the minds of the men in charge of the work. Its applications to smoke abatement, in many cases, are quite indirect, but all the results which are put into practical use tend toward lessening smoke. This is a very comprehensive problem and its completion will take some time.

The principal organization doing general research work on coal in Great Britain is the Fuel Research Board of H. M. Department of Scientific and Industrial Research. Sir George Beilby is in charge of this Board. The work which is being carried out on low-temperature carbonization is mentioned on page 45. Besides this activity, the Research Board is making a comprehensive survey of the fuel resources of the United Kingdom. This includes the estimation of the available supply, the present rate of use, chemical and physical analyses, and an estimation of what the most valuable uses are for each fuel; for instance, one coal will be recommended for low-temperature carbonization, another for steam-raising, another for the manufacture of metallurgical coke, etc. In addition to the work of the Fuel Research Board, the universities have active fuel departments carrying on extensive inquiries.

The problem which is receiving most attention from all is the low-temperature carbonization of coal. Probably next in interest is coal flotation, a process for the cleaning of finely-divided coal by the use of methods

similar to those used in the concentration of copper ores. There are facilities for doing research in this field in all the universities and in most of the large research organizations. The results which are being obtained seem to point to a successful use of the flotation process on a large scale in the near future. Indeed, a few plants are already operating it on a commercial scale, one of the most successful being the Skinningrove Iron Works.

Another research development of considerable interest is the study of the properties of coal as shown by microscopic examination. James Lomax, of the Lancashire and Cheshire Coal Research Association, has done the most valuable work along this line. He has developed a method for the preparation of sections which is very useful, and has been able to draw certain valuable conclusions from the examination of these sections. He has claimed that, by microscopic examination, he can ascertain more about the properties and value of an unknown coal than can be determined in any other way except by actual commercial test. The work in this direction is undoubtedly a distinct advance; it seems that it will be partly applicable to the proper development of low-temperature carbonization.

At the University of Manchester, Dr. Fishenden has carried out some very valuable experiments on the efficiency of the different fuels in various forms of household appliances. Her results give accurate knowledge on many important points which were formerly matters of conjecture. She has shown that the heating of a room by an open fire is almost entirely due to radiant heat. The radiant efficiency of soft coal is from 20 to 24 per cent. in different grates; of coke, 24 to 28 per cent.; and of low-temperature coke, 30 to 34 per cent. She has drawn valuable conclusions as to the proper forms of heating apparatus and the methods of handling them.

List of Authorities Consulted*

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